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AN APPROACH TO A MODULAR SYSTEM-ORIENTED DISCHARGE-CHARGE CONTROLLER FOR AUTOMATED POWER-SOURCE EVALUATION

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GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

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ABSTRACT

Because all subsystems depend on the power sources of a spacecraft, the designs need to be adequate and reliable. This report discusses the studies and methods of a space power field group for controlling experiments with a discharge-charge controller. During the evaluation, some pertinent problems were found in the remote and local programming, remote voltage-sense switching circuits, ac power failure, load-switching relay current surges, and inadequate fail-safe protection. Design methods are suggested for resolving or minimizing each problem area.

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*Suppressed (Not function).

AN APPROACH TO A MODULAR SYSTEM-ORIENTED DISCHARGE-CHARGE CONTROLLER FOR AUTOMATED POWER-SOURCE EVALUATION

INTRODUCTION

The power system design of a spacecraft is fundamental because all missions need an adequate and reliable power source on which all subsystems can depend. Rechargable electrochemical cells connected into a battery (charged from solar cells connected into a solar array) are used for most spacecraft power systems because they are efficient, reliable, and of proven designs. Considerable knowledge was gained over the past decade in designing and applying these systems to meet spacecraft power needs.

Designing and testing these systems require that the batteries be charged and discharged periodically to develop parameters necessary to design peripheral equipment or for establishing requirements for new kinds of cells, and to maintain the desired chemical structure of the cells.

A discharge-charge controller (a battery cycler) was used to exercise the battery in these tests. A basic battery cycler consists of a charging source and a discharging sink, both controlled by a cycle timer. A more useful cycler usually provides controlled charge and discharge—independent of battery changes—and programmed charge-discharge levels and cycles.

Figure 1 shows how two regulated power supplies were connected in a previously used simple cycler. A motor-driven cam timer provides charge-discharge switching once per cam revolution. The charge power supply provides a constant charging current until the terminal voltage of the battery reaches a maximum level, and then only the current necessary to maintain that level. Circuit control was provided by a commercially available regulated power supply. The discharge supply was connected in series with the battery being tested, and the resistor was adjusted to maintain an approximate 5-volt drop for the necessary current and the expected battery voltage. Thus, the regulated supply controls the discharge load on the battery.

The use of two power supplies was uneconomical because a single supply will suffice if the polarity is switched and the current level changed. Resistor programming has been available on commercially available power supplies; therefore, the dual-supply cycler (Figure 1) was replaced with the single-supply cycler (Figure 2).

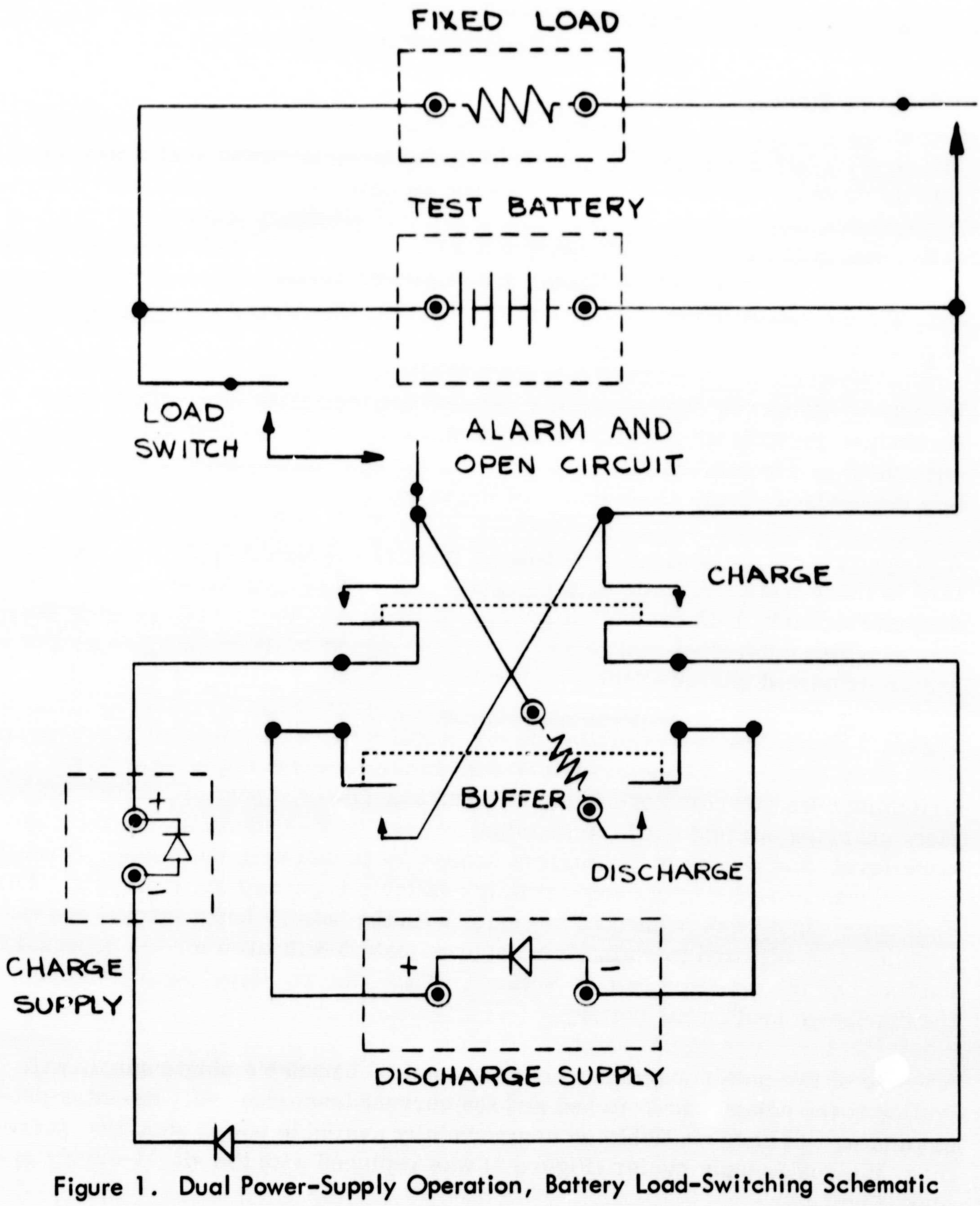


Figure 1. Dual Power-Supply Operation, Battery Load-Switching Schematic

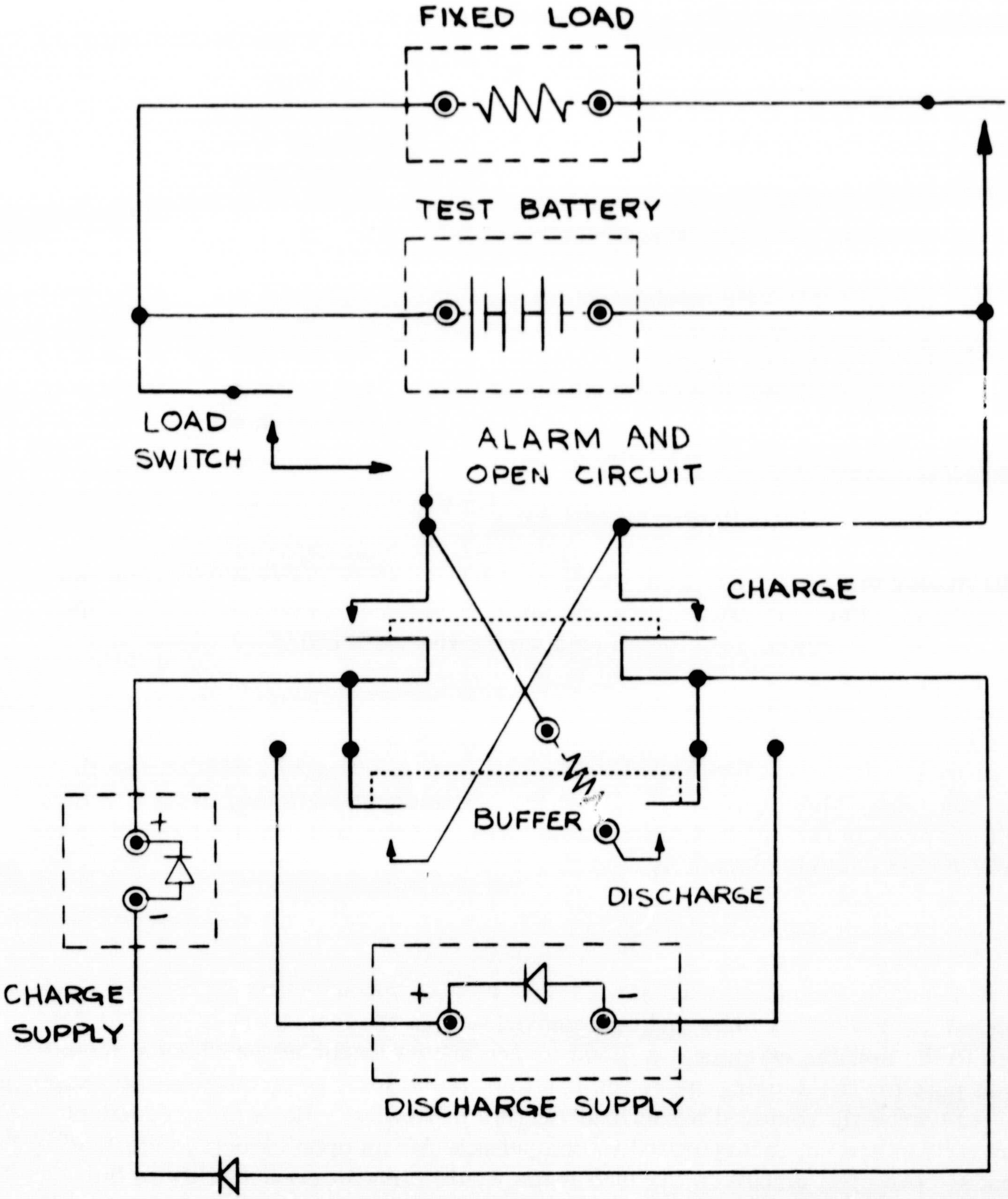


Figure 2. Single Power-Supply Operation, Battery Load-Switching Operation

Cycler control progressed from early motor-driven cam switches to programmed systems coupled to an external controller for synchronizing other parts of the experiment. The controllers range from stepping switch-driven diode-matrix decoders to small computers.

This battery cycler was designed to:

- Eliminate failure modes discovered in previous testing
- Increase reliability through experience
- Develop fail-safe mechanism for unattended operation
- Develop system modularly to allow easy interface of new power supplies (i.e., digitally programmed) and remote controllers (i.e., computers) while maintaining an autonomous local-programmed mode

BATTERY-CYCLER PROBLEM AREAS

The cycler problem areas were studied in detail before the cycler design was completed. Each fact was fully considered to help design hardware of the quality needed. Pertinent problems found during the tests follow.

Remote and Local Programming

A study of battery cyclers indicates that most designs applied only to specific applications. Most cyclers employed local or manual-switching control, which did not provide the accurate repeatable switching available in most remote programmable equipment designs.

Remote Voltage-Sense Switching

Power-supply manufacturers specify that remote voltage-sense circuits be connected after the load lines and be removed before the load lines to prevent damage to the sensing circuits. A diode or resistive component provides a redundant path for the sensing operation if either of the local or remote-sense leads is inadvertently removed while load current is flowing. However, redundant provisions are not incorporated to compensate for an open circuit in the load leads. (An open circuit in the load leads would allow current to flow in the remote-sense leads, proportionally to the output current level of the power supply.)

Failure of ac Current

Design methods often incorporate switching circuits that require synchronous switching of the ac input and the load current to the test battery. The supply will dissipate battery power if the battery is connected to the output terminals of the power supply before the supply is connected to ac power. Examination of the supplies switched this way, however, often indicates internal circuit damage or failure.

Load-Switching Relay-Current Surges

If improper load-switching procedures are used, relay contacts are often subjected to destructive current surges. Connecting a discharged battery to an active power supply allows inrush-surge currents that often weld mechanical relay contacts or cause detrimental arcing conditions with mercury-supporting contacts. Switching a battery from a discharge to a charge mode can also generate harmful inrush-current surges.

Inadequate Fail-Safe Protection

Unwarranted current paths to the test-battery terminals (commonly caused by welded relay contacts), erroneous switch signals, and component fatigue allow spurious currents to flow and often place excessive strain on the battery. Spurious current flow is often undetected during shut-down periods or open-circuit conditions. When real-time monitoring is not used, test results are sometimes destroyed by conditions encountered during an environmental evaluation of a test battery. Each critical characteristic (e.g., temperature, pressure, terminal voltages, line current) can create failure levels that destroy test results if not detected and eliminated by real-time monitoring.

EXPERIMENTAL BATTERY-CYCLER DESIGN

Modular Design by Functional Block

The program objective was to design a unit containing semiindependent modular sections to facilitate programming and updating. The modular concept was used to enable electrical and mechanical access for checkout, repair, or replacement. Access to the input programmer enables program changes or program inputs governed only by the capability of the input device.

Sequential Switching

A programmable sequentially timed switching procedure was selected to switch the remote voltage-sense leads to the remote position only after the load leads were connected to the battery. The timing sequence also reconnects the voltage-sense leads to the local position of the power supply before any load leads are

disconnected. Normally closed control-relay contacts were selected to provide a method of enabling local-sense programming during dc failure of the control-relay coil. This mode of operation is also present during loss of ac. (Loss of ac causes the unit to remain latched in the local mode until it is reset manually by a reset and restart command.)

Reverse-Current Protection

To protect the power supply from reverse current, a method to incorporate a memory and timing capability was designed to allow ac turn-on circuit timing to vary, but not to endanger the battery or allow its power to be dissipated in the power supply. The turn-on circuit must also protect the supply during any load-switching time set by a sequencer. To accomodate most switching, blocking or by-pass methods were used to eliminate all objectionable currents.

Sequential Load-Current Relay Switching

To obtain the most durable and reliable load-current switching, circuitry high-current switching was segregated from no-current switching. Restricting the high-current work cycle to a minimum number of components reduces the component-failure risk and permits a wider choice of relays for the fail-safe circuitry. This method also allows preventative maintenance procedures to be tailored to each relay category.

Safe-Condition Alarm

A mechanism was needed to put the experiment in an open-circuit condition to respond to a failure signal from the computer. The design of this mechanism should include a memory and locking feature capable of storing and transferring an alarm signal to the unloading section of the load-switching circuits. A remote-reset circuit is also required for resetting the experiment after detection and correction of the alarm signal. This unit must have circuitry for terminating operations during an equipment malfunction (i.e., loss of ac or dc, or broken cable, etc.) and for indicating (by using a light panel) the mode in which the cycler was programmed at the time the alarm circuit was enabled.

DESCRIPTION OF EXPERIMENTAL CYCLER

An experimental cycler, or discharge-charge controller prototype, was designed using a seven-module concept. Figure 3 shows the substructure of the battery cycler, indicating the interconnection pattern between units. Each unit is partially enabled by switching a dc voltage to facilitate examination before actual startup. A manual reset command to the controller starts the sequencer,

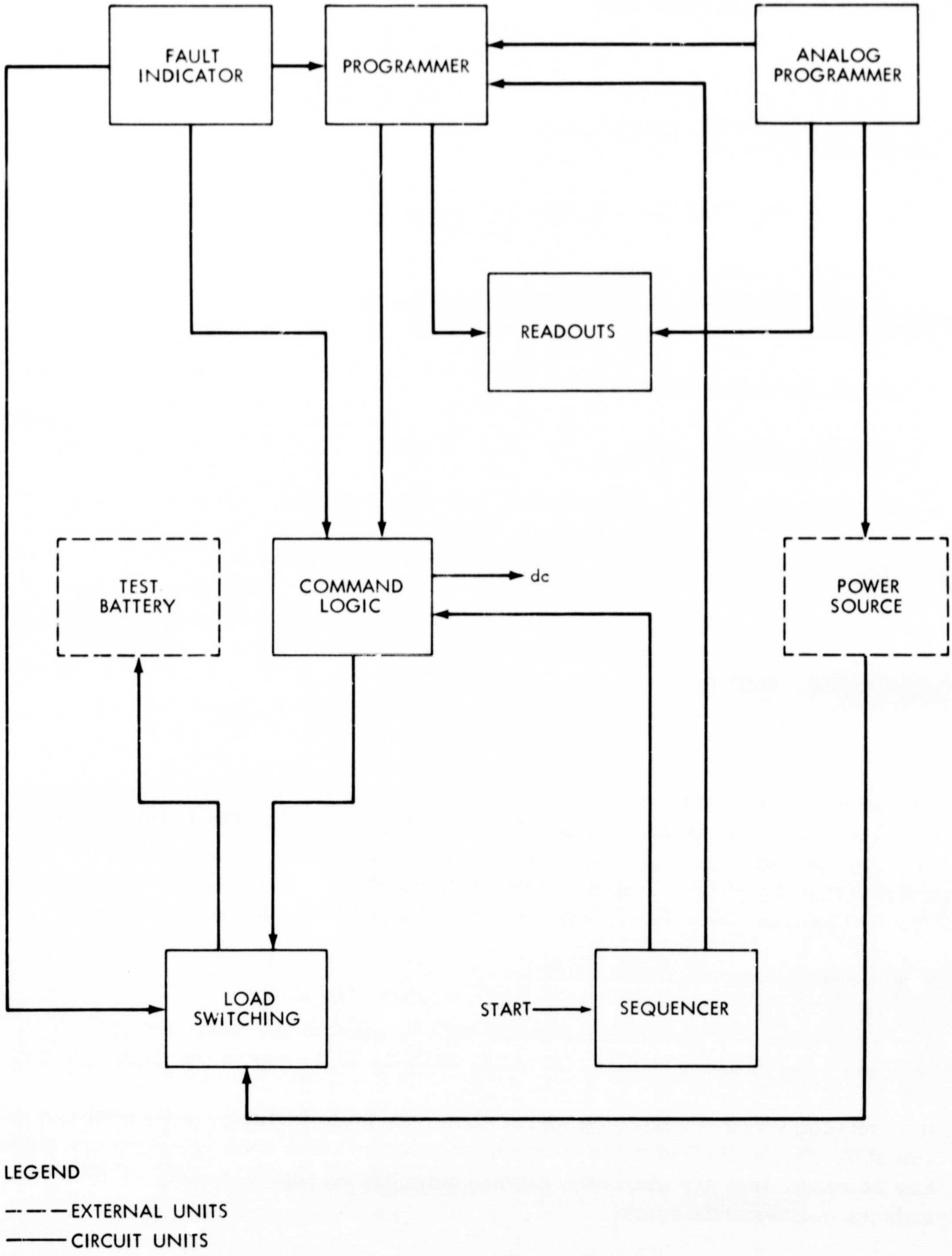


Figure 3. Battery-Cycler Diagram

resets the command-logic unit to a NO-GO or open-circuit condition, and simultaneously enables the -24 vdc circuit to the command-logic programmer and analog-programmer units. Ten positions of the logic and analog programmers are preprogrammed to accomodate any one of the following modes:

- Discharge-fixed load
- Discharge-constant current
- Charge-remote sense
- Charge-remote sense with fixed load
- Charge-constant current
- Open circuit

A programmable skip bus is provided, allowing any combination of 10 positions to be skipped. After the preprogram selections are made and the sequencer is enabled with a start command, the cycler will begin operations. The command-logic unit is enabled by a sequential time pulse ANDED with a programmer command to the load relays. The controller will step to new modes of operation when the sequencer is enabled with a scan-advance command. The following paragraphs briefly describe each subunit.

Programmer

The programmer consists of a 10- by 10-input matrix board with Y-axis inputs actuated by a signal from a 10-position stepping switch located in the analog-programmer unit. The X-axis contains six output levels programmed with a pin intersecting the X- and Y-axes. One of the programmed levels is transferred to the command-logic unit by way of a timed pulse from the sequencer.

Sequencer

The sequencer is a synchronous motor-driven reed relay-rotary switch controlled by two latching relays. A solid-state model is now in the design stage.

A reset-start or scan-advance signal (from the fault-indicator unit) with alarm actuated will enable one rotation of the sequencer. The reed relay-rotary switch has 24 relays that are used as a serial chain, timed approximately 40 milliseconds ±2 milliseconds apart.

Analog Programmer

The analog programmer functions as a remote controller for the power supply. This modular section contains a rotary stepping switch, two banks of potentiometers, and two control relays. The stepping switch contains 12 banks of gold-plated contacts, 10 positions per bank. Ten of the banks have make-before-break contacts to facilitate the switching of 10 current and 10 voltage-control potentiometers. Make-before-break contacts are essential for a linear switch transition from one control level to the next to compensate for the fast response time inherent in most power supplies. Ten-turn wire-wound precision potentiometers with resolution greater than 0.05 percent ±0.2-percent linearity were selected to maintain control specifications of the discharge-charge power supply. One control-relay unit is designed to shunt the programmed voltage and current potentiometers, dropping the output of the power supply during transition from one program position to the next one. The second control relay, controlled by the command-logic section, switches the remote voltage-sense leads of the power supply to either a local or remote position.

Command Logic

The command-logic section consists of gated-storage relays (latching relays) controlled with signal levels enabled by the programmer and the signal pulses received from the sequencer. This combination gives the critical-timed load switching. Table 1 lists the cycler modes with their scan time.

Load Switching

Heavy-duty relays mechanize the load-switching section. Six relays are used to route the battery load current systematically as predetermined by the four previously discussed subunits. A critical design feature is switching the current by the contacts of one relay, centralizing the periodic check and replacement to one relay. Restricting the current switching to the one relay increases the contact life and dependability of the remaining relays, improves reliability of the remaining relays when used for failsafe protection, and decreases contact problems.

Fault Indicator

The fault indicator is designed with special circuits to actuate with data-signal alarms, loss of ac or dc, and to provide proper resetting before operations begin. The data-signal-alarm relay detects -24 vdc from a level comparator within the data-acquisition system, or a component or power failure within the data-acquisition system. During this time, critical switching commands disconnect the test battery from the load lines, open the load lines to the power supply, and

Table 1

Critical-Timed Load Switching

Cycler Modes	Scan Time				
	T+13	T+14	T+15	T+16	T+17
Charge-remote sense	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, $\overline{\mathrm{KL100}}$, $\overline{\mathrm{KL3}}$, KL5	$\overline{\mathrm{K50}}$	K2
Charge-remote sense, fixed load	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, KL100, $\overline{\mathrm{KL3}}$, KL5	$\overline{\mathrm{K50}}$	K2
Charge-constant current	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, $\overline{\mathrm{KL100}}$, $\overline{\mathrm{KL3}}$, KL5	$\overline{\mathrm{K50}}$	
Discharge-constant current	$\overline{\mathrm{K2}}$	K50	KL4, KL2, $\overline{\mathrm{KL100}}$, $\overline{\mathrm{KL3}}$, KL5	$\overline{\mathrm{K50}}$	
Open circuit	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, $\overline{\mathrm{KL100}}$, KL3, KL5	$\overline{\mathrm{K50}}$	
Discharge-fixed load	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, KL100, KL3, KL5	$\overline{\mathrm{K50}}$	
Alarm	$\overline{\mathrm{K2}}$	K50	$\overline{\mathrm{KL4}}$, $\overline{\mathrm{KL2}}$, $\overline{\mathrm{KL100}}$, KL3, KL5	$\overline{\mathrm{K50}}$	

open the resistive-fixed load. This operation also switches the remote voltage-sense lines to the output terminals of the power supply. Loss of ac or dc enables the alarm relay, and unlatches the -24 vdc which disables the -24 vdc control circuitry.

The main current-switching relay is programmed to switch loads for all modes except the loss of ac or dc (alarm condition). Return of input power to the controller will not restart operations until the proper restart procedures are followed. The 6-vdc source to the readout section indicates the mode in which the alarm circuit was enabled. Actuating the reset switch resets the command-logic section, enables the -24 vdc circuit, and programs the controller to the open-circuit mode. Operations will resume when the new program is set into the programmer matrix, with the position-advance switch and a local or remote scan-advance pulse in the sequencer section.

Readouts

To visually monitor the program or to preview preset conditions before actual operations, a bank of indicator lights (visual display lamps) was selected. These lights indicate the mode of operation, the method of operation, and the position programmed. Red and green color-back grounds were selected for visual use, permitting identification of a discharge or charge program, or an open-circuit condition by the absence of the red and green grounds.

BATTERY-CYCLER TEST RESULTS

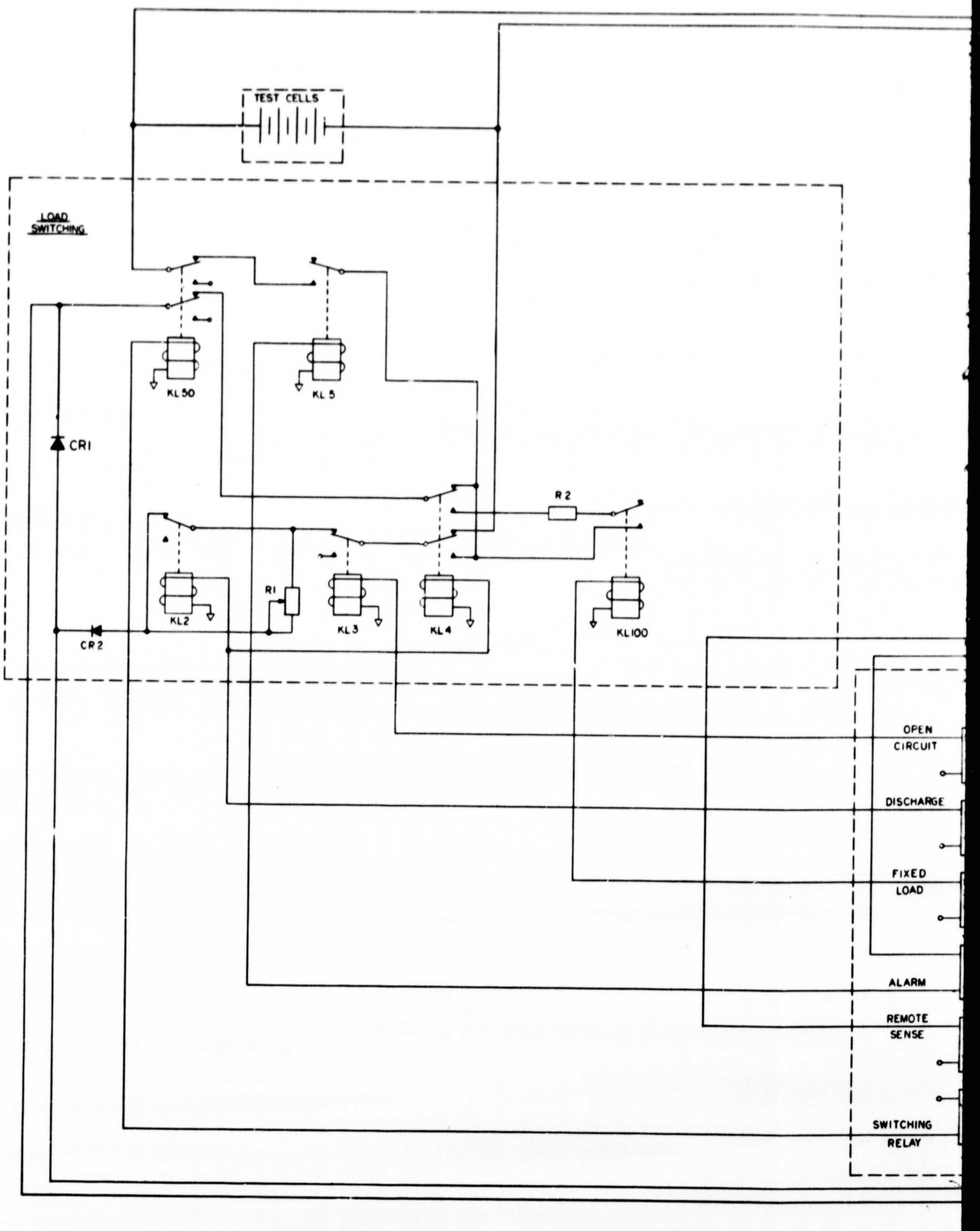
A prototype of a discharge-charge controller was used to obtain the data in this report. (Recording charts were obtained with a Mark-200 brush recorder.) Figure 4 shows the logic of the discharge-charge controller; Figure 5 is a schematic of this controller. Unless specified otherwise, the data points are:

- Recorder pen positions:

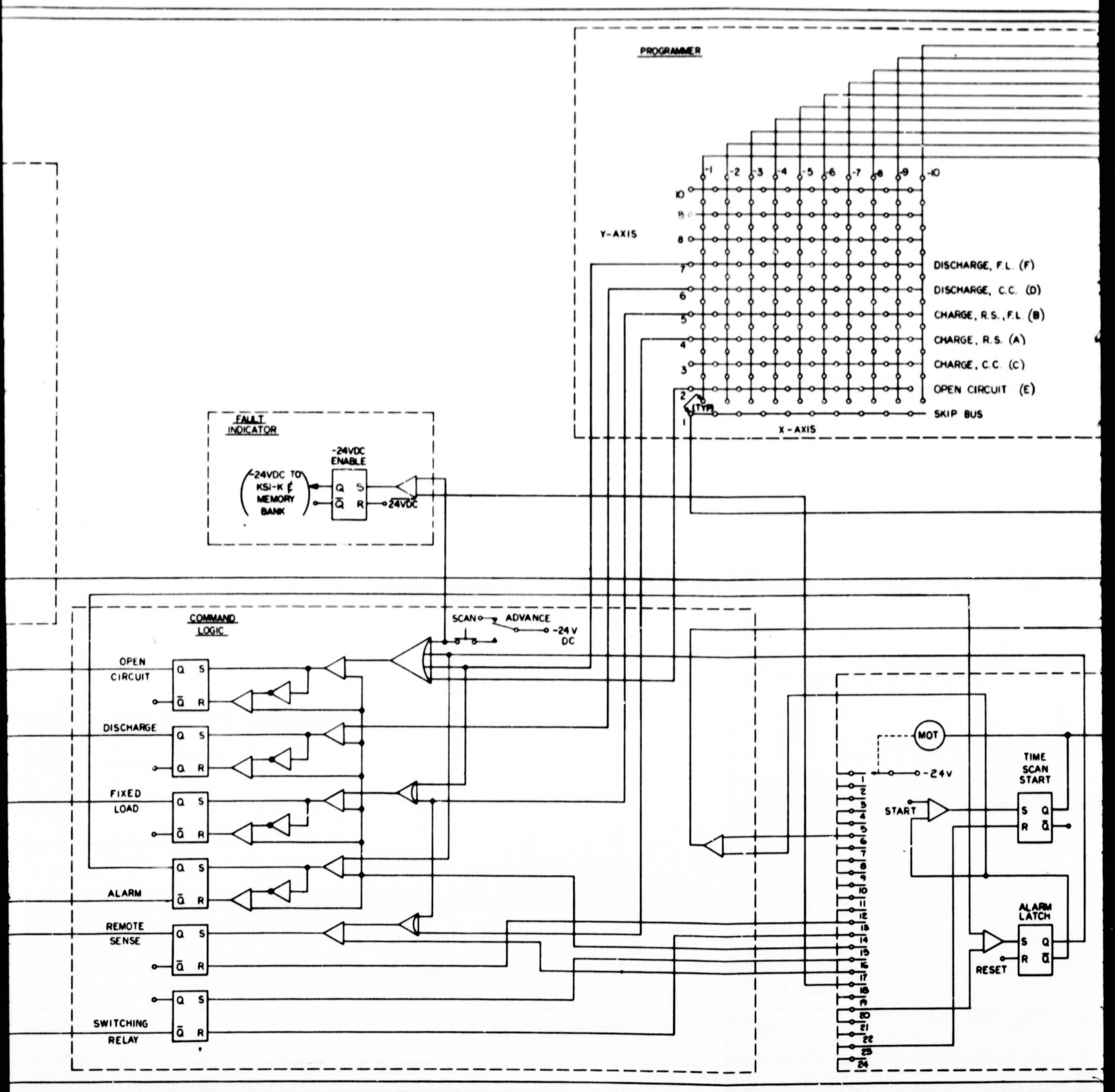
Pen No.	Data Point
1	Sequencer scan
2	Analog-programmer scan
3	Remote-sense relay (K-2)
4	Load-switching relay (KL-50)
5	Discharge relays (KL-2, 4)
6	Alarm relay (KL-5)
7	Open-circuit relay (KL-3)
8	Load current (1 amp/div)

- Chart speed: 100 mm/sec or 0.05 sec/horizontal div

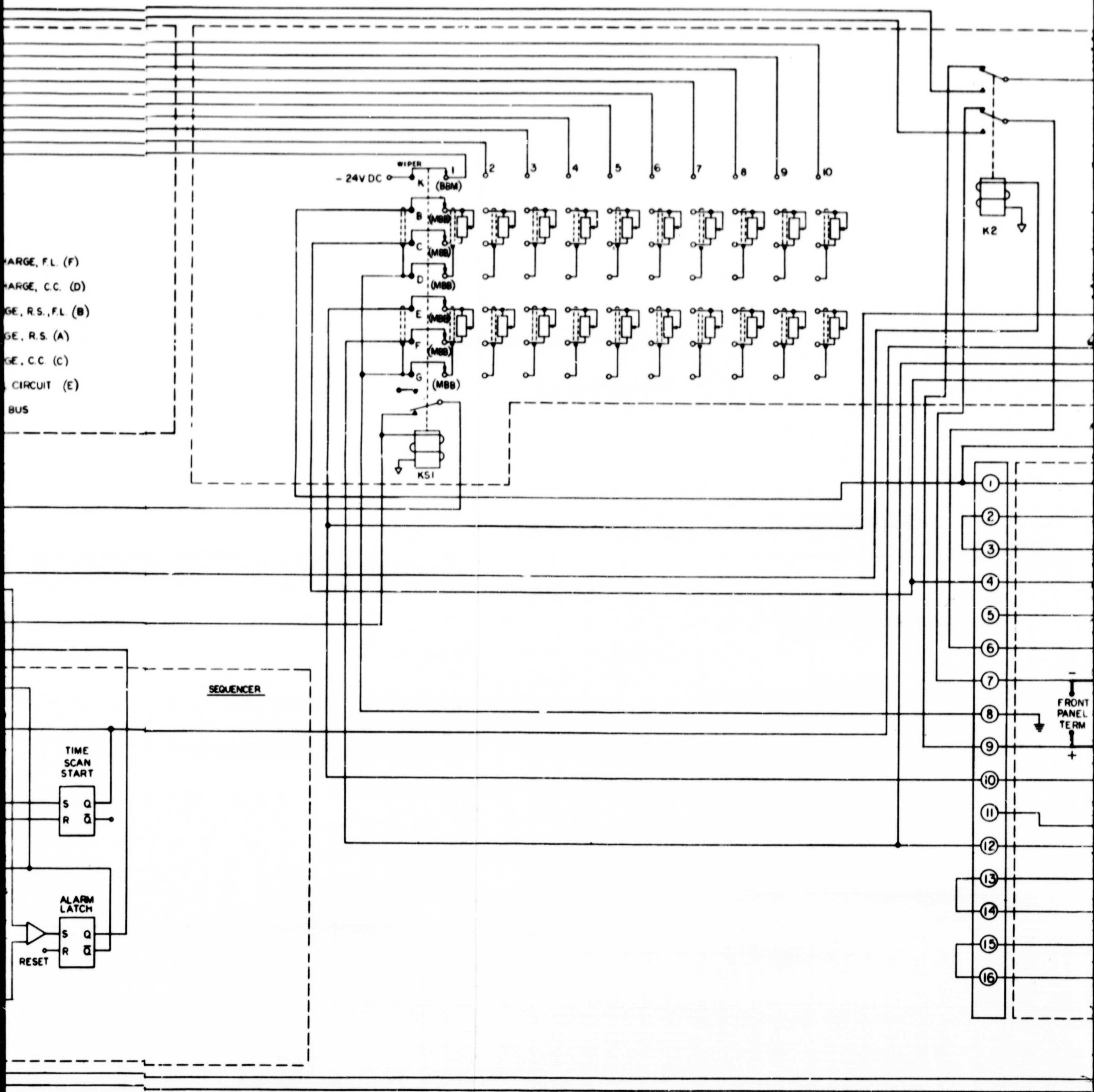
Because of the limited time, component lead time, etc., this report is presented in basic form only. Because the timing pulses were measured across the relay coils, they indicate relative timing caused by hysteresis, actuation of the relay, etc.



FOLDOUT FRAME 1



FOLDOUT FRAME 2



FOLDOUT FRAME 3

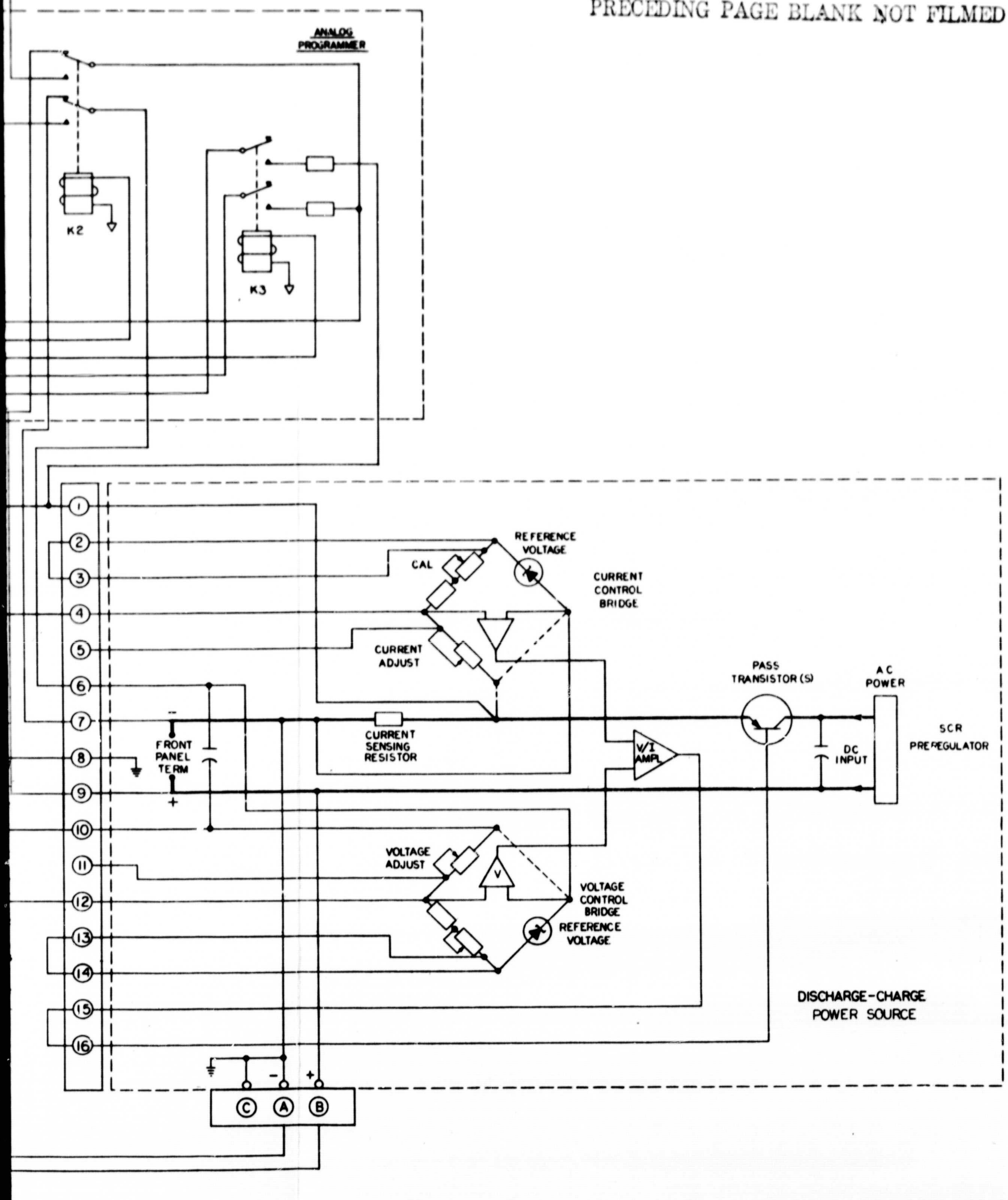


Figure 4. Battery Discharge-Charge Controller Logic Diagram

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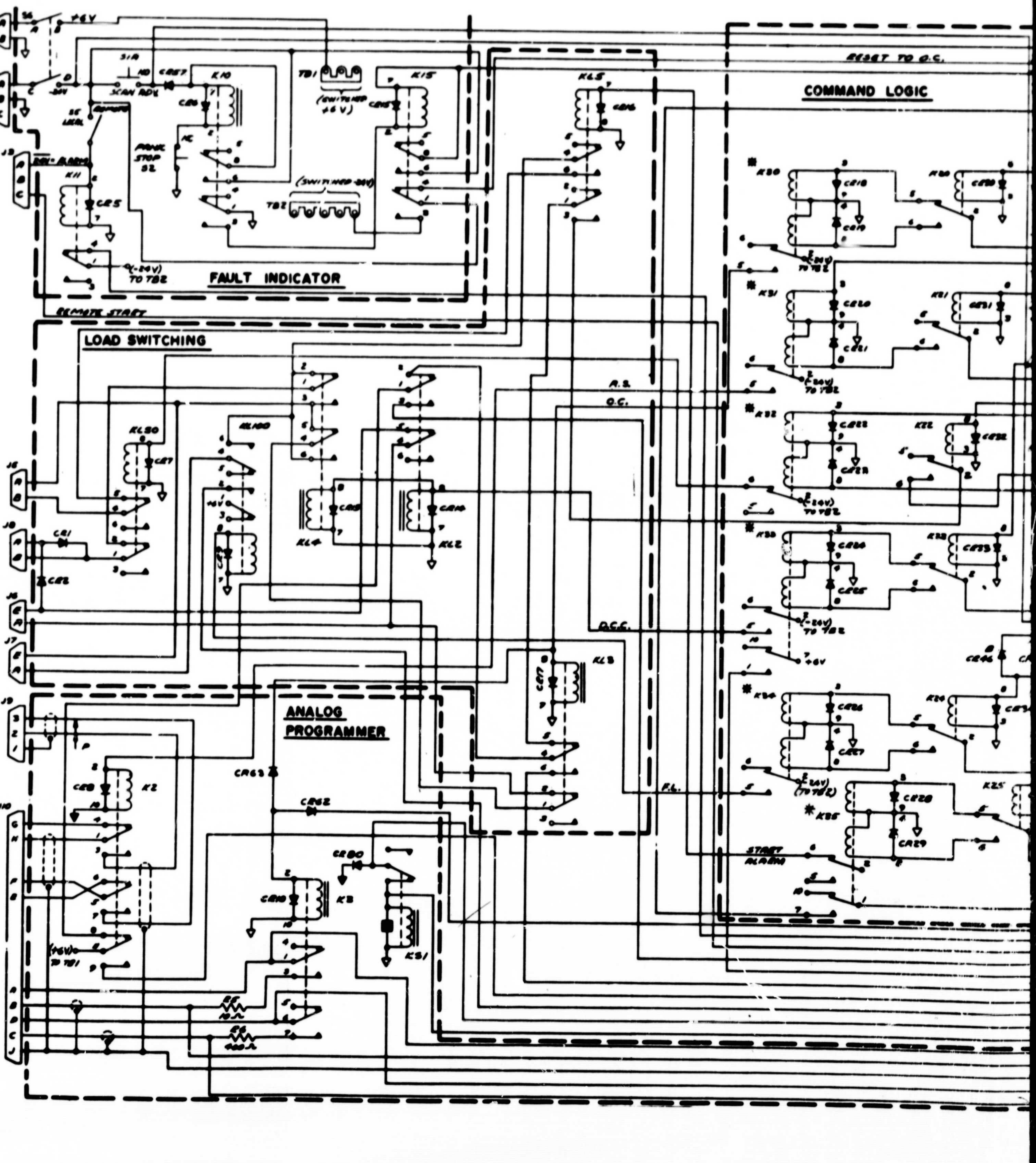
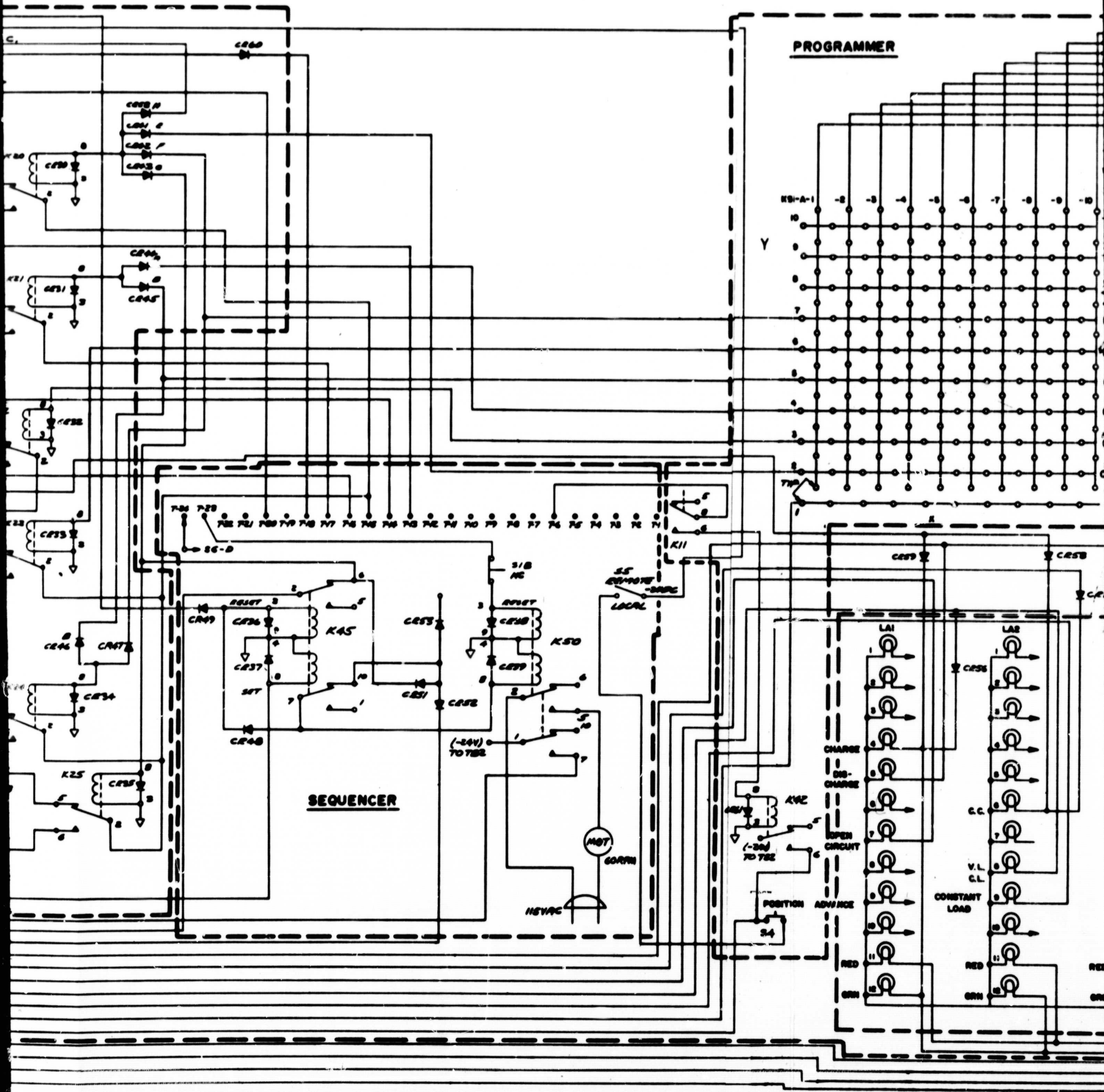


OLDOUT FRAME 1



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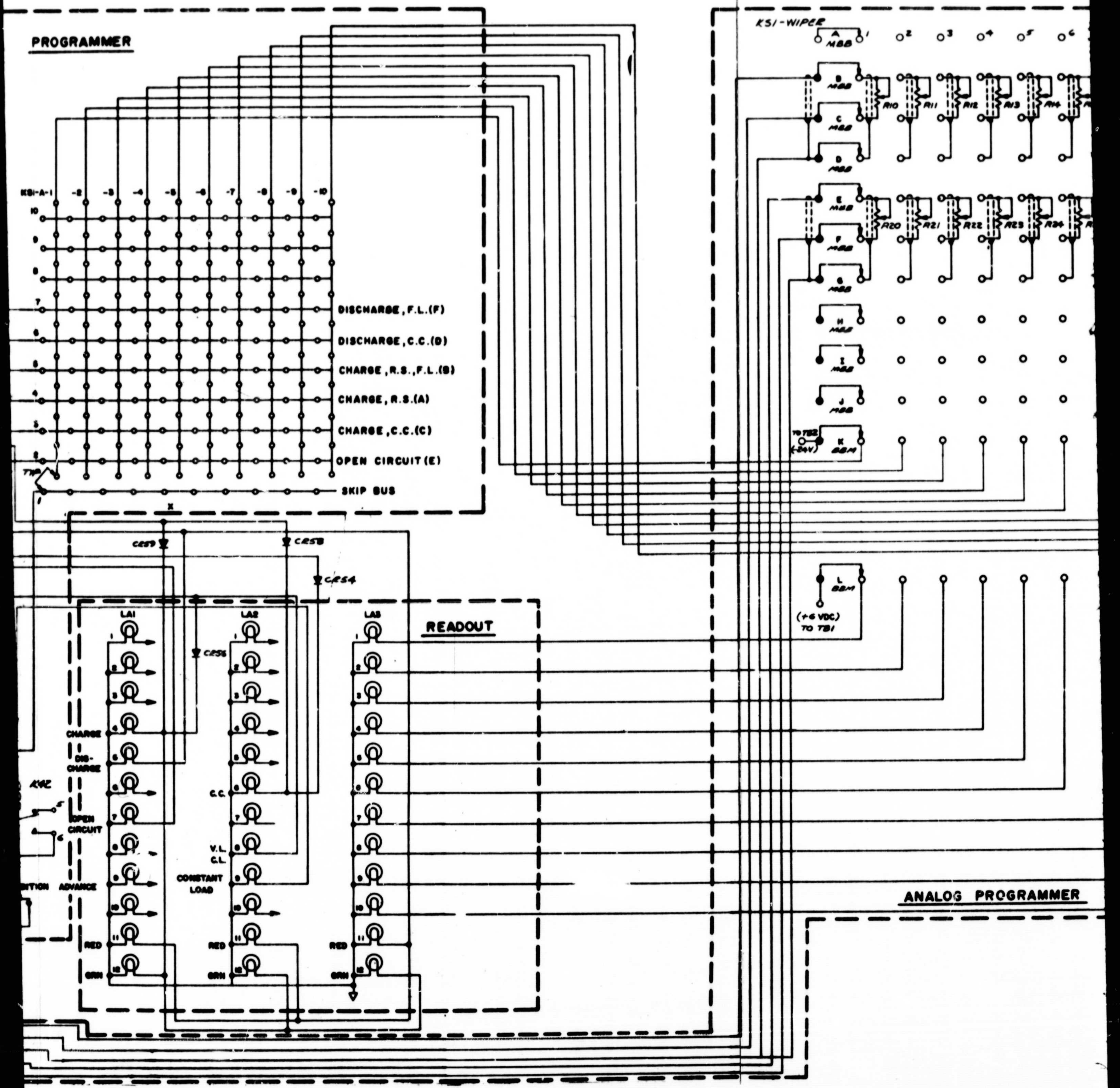
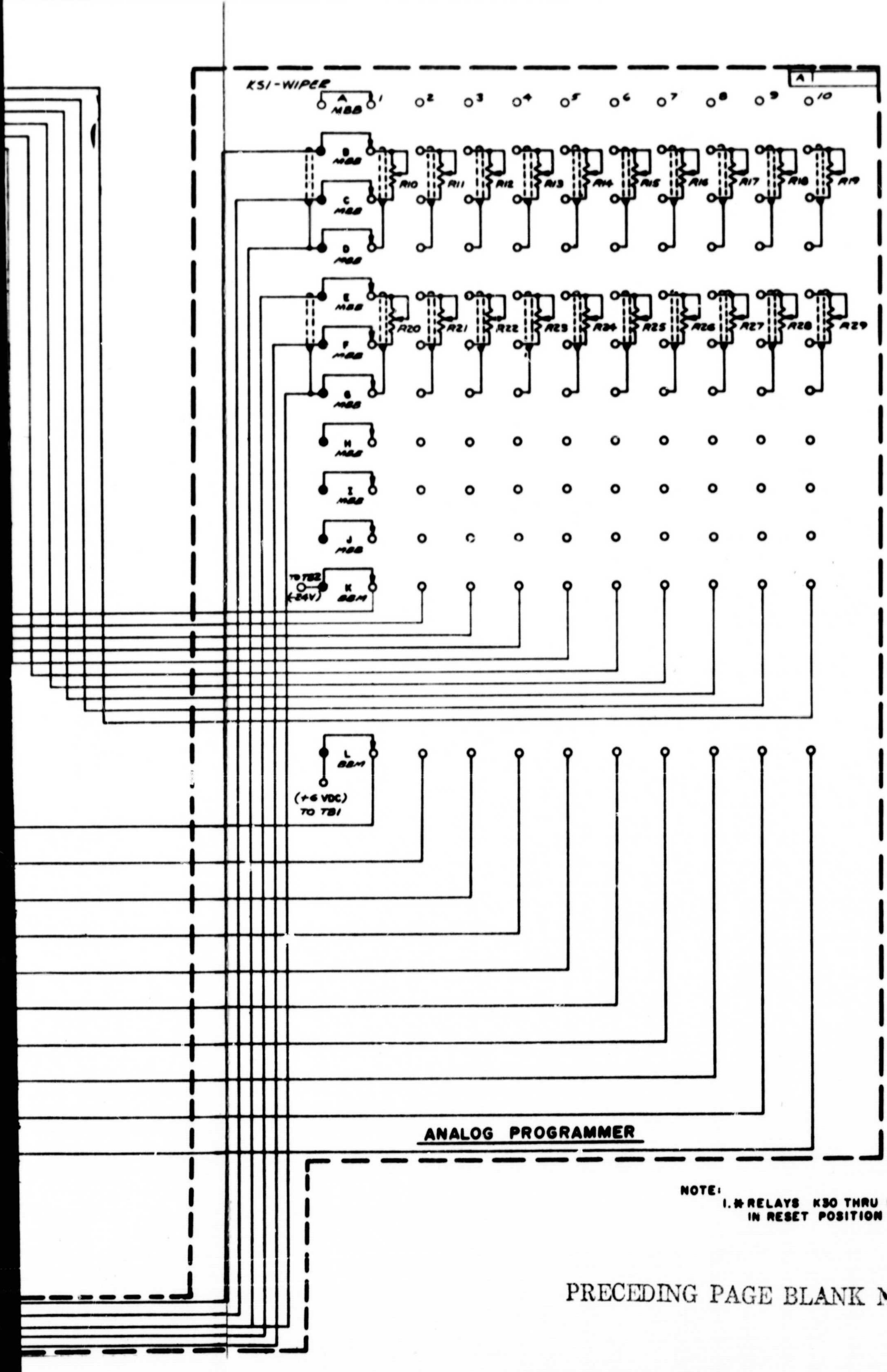


Figure 5. Battery Discharg

FOLDOUT FRAME 3

FOLDOUT FRAME 3



NOTE:
1.* RELAYS K30 THRU K35 ARE SHOWN IN RESET POSITION

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Figure 5. Battery Discharge-Charge Controller Schematic

Operational Methods

The timing sequence used in the cycler, a product of the programmer section, is channeled to the final load-switching sections. Figures 6, 8, 10, 12, and 14 show the relay-switching operations and list the timing events related to a selected operational mode transition. Each figure shows all actual operational conditions except load currents (shown in other figures). Figures 7, 9, 11, 13, and 15 show the operational condition of the load relays before and after each transition for Figures 6, 8, 10, 12, and 14 (i.e., Figure 7 is the schematic for Figure 6 chart).

Power-Supply Protection

Capacitive-type spacecraft batteries cause problems uncommon to resistive-type loads. Capacitive and related inductive-kickback currents are prevalent in battery-evaluation instrumentation. Figures 16 through 31 show some test procedures and hardware designs that add to the suppression of harmful current surges and paths. Three major problems are:

- Inrush current—current developed from the test battery through the power supply during load switching and ac interrupts

- Reverse current—current flow from the test battery through the power supply in the discharge mode during ac interrupts and power-supply failure

- Current spikes—currents generated during load-current switching

Inrush Current—Figures 16, 17, 18, and 19 show the necessity of the blocking protection that silicone diode CR 2 provides. A problem encountered caused the experimenter to question the use of the ac turn-on procedure (actuated by automatic controls of a power supply and a discharge-charge controller). Procedures require that the ac power to the power supply be on only when the battery is connected. Without diode CR 2, a current spike of approximately 25 amps (arrow 4, Figure 18) develops when a 5-cell test battery is connected in the load line before the ac current is applied to the power supply. Figures 16 and 18 are shown in the charge-constant current mode of operation to depict a continuous connection between the test battery and the power supply before any charge condition occurs. Compare the blocking effect (no current spike) of protective diode CR 2, shown by arrow 4 of Figure 16, to the spike shown in Figure 18. To use this type of circuit requires a modification in the power supply. The specified IR drop for each lead between the power supply and load is usually 0.5 volt. To compensate for the 0.7-volt drop of CR 2, it is necessary to series two diodes between the differential sense amplifiers (of the power supply) and each respective

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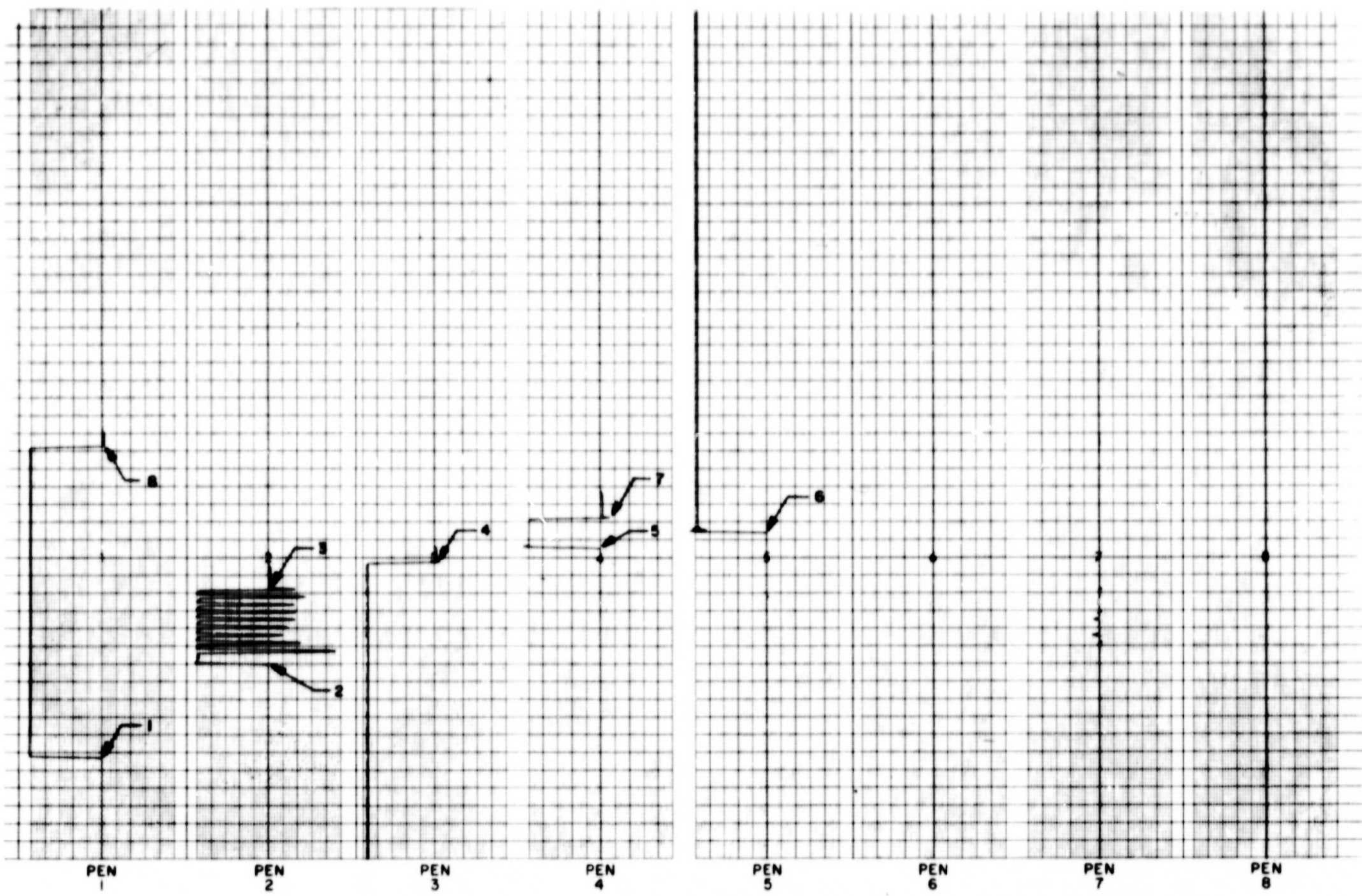


Arrow	Operation
1	Sequencer actuated
2	Programmer started
3	Programmer stopped
4	Remote-sense lines switched from the test battery to the power-supply output terminals
5	Positive load line L_1 disconnected
6	Test battery switched to a discharge position
7	Positive load line L_1 connected
8	Sequencer scan completed

Figure 6. Charge-Remote Sense to Discharge-Constant Current Chart

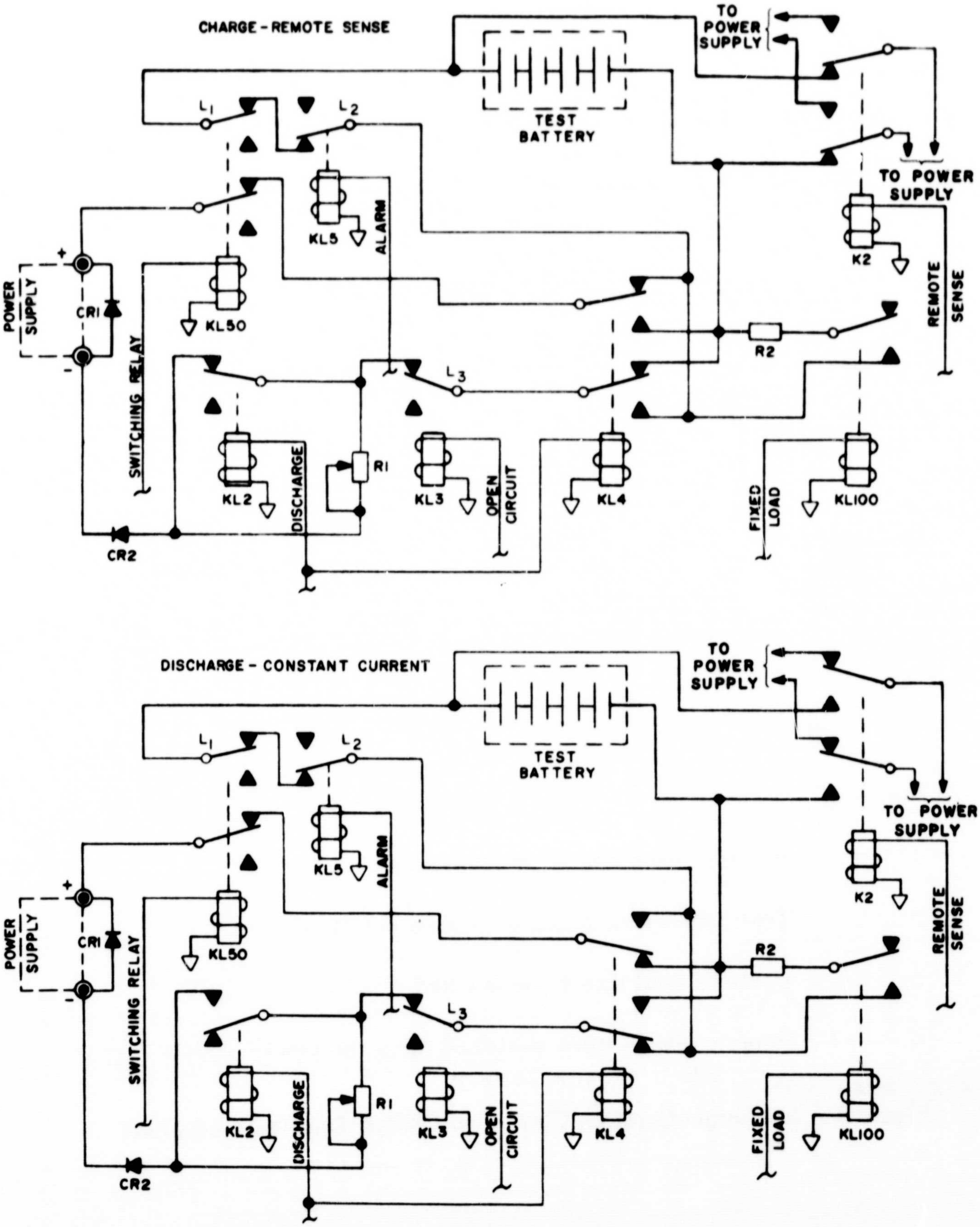
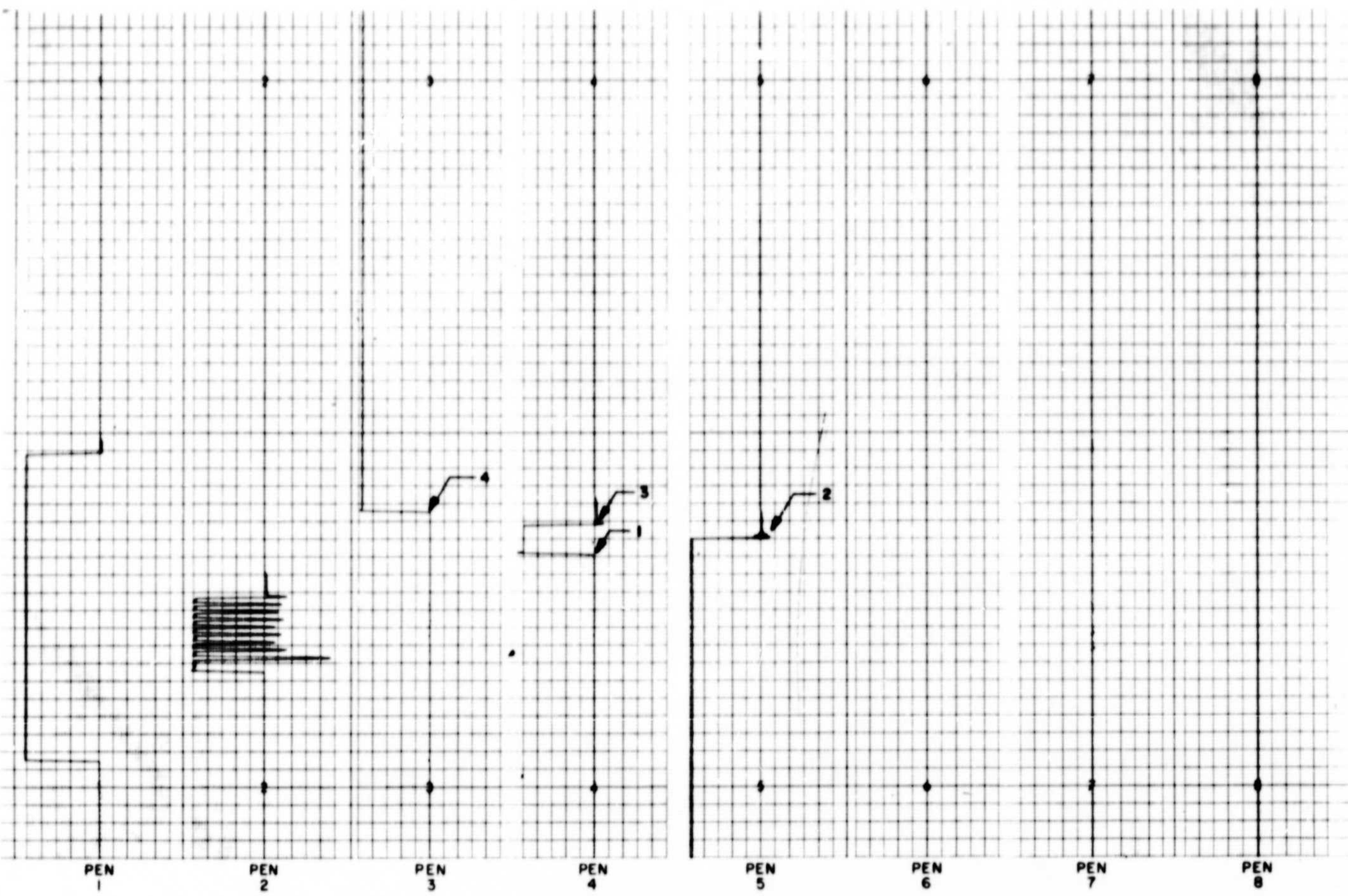


Figure 7. Charge-Remote Sense to Discharge-Constant Current Schematic



Arrow	Operation
1	Positive load line L_1 disconnected
2	Test battery switched to charge position
3	Positive load line L_1 connected
4	Remote-sense lines switched form the power-supply output terminals to the test battery

Figure 8. Discharge-Constant Current to Charge-Remote Sense Chart

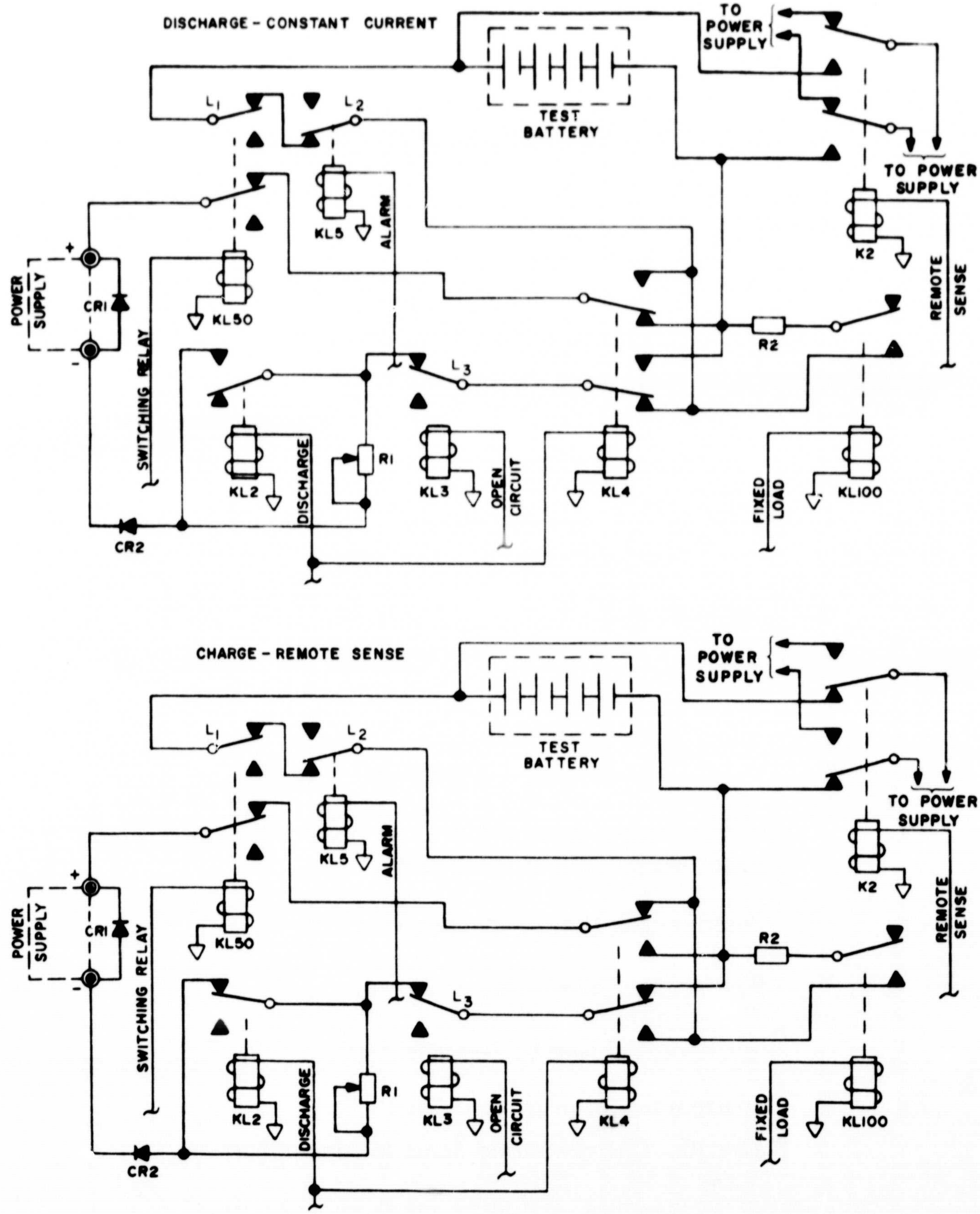
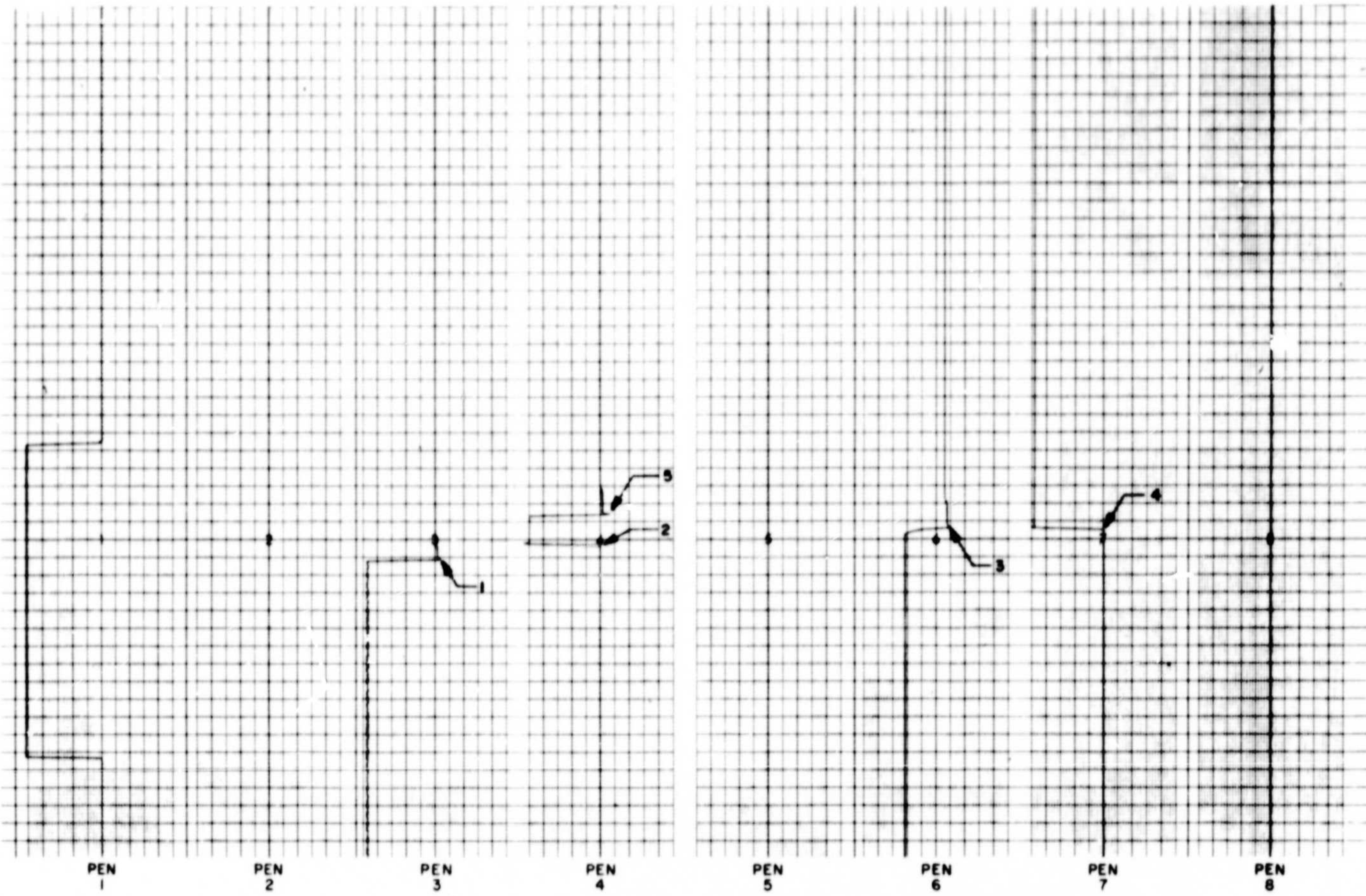


Figure 9. Discharge-Constant Current to Charge-Remote Sense Schematic



Arrow	Operation
1	Remote-sense lines switched from the test battery to the power-supply output terminals
2	Positive load line L_1 disconnected
3	Positive load line L_2 disconnected
4	Negative load line L_3 disconnected
5	Positive load line L_1 connected

Figure 10. Charge-Remote Sense to Alarm Chart

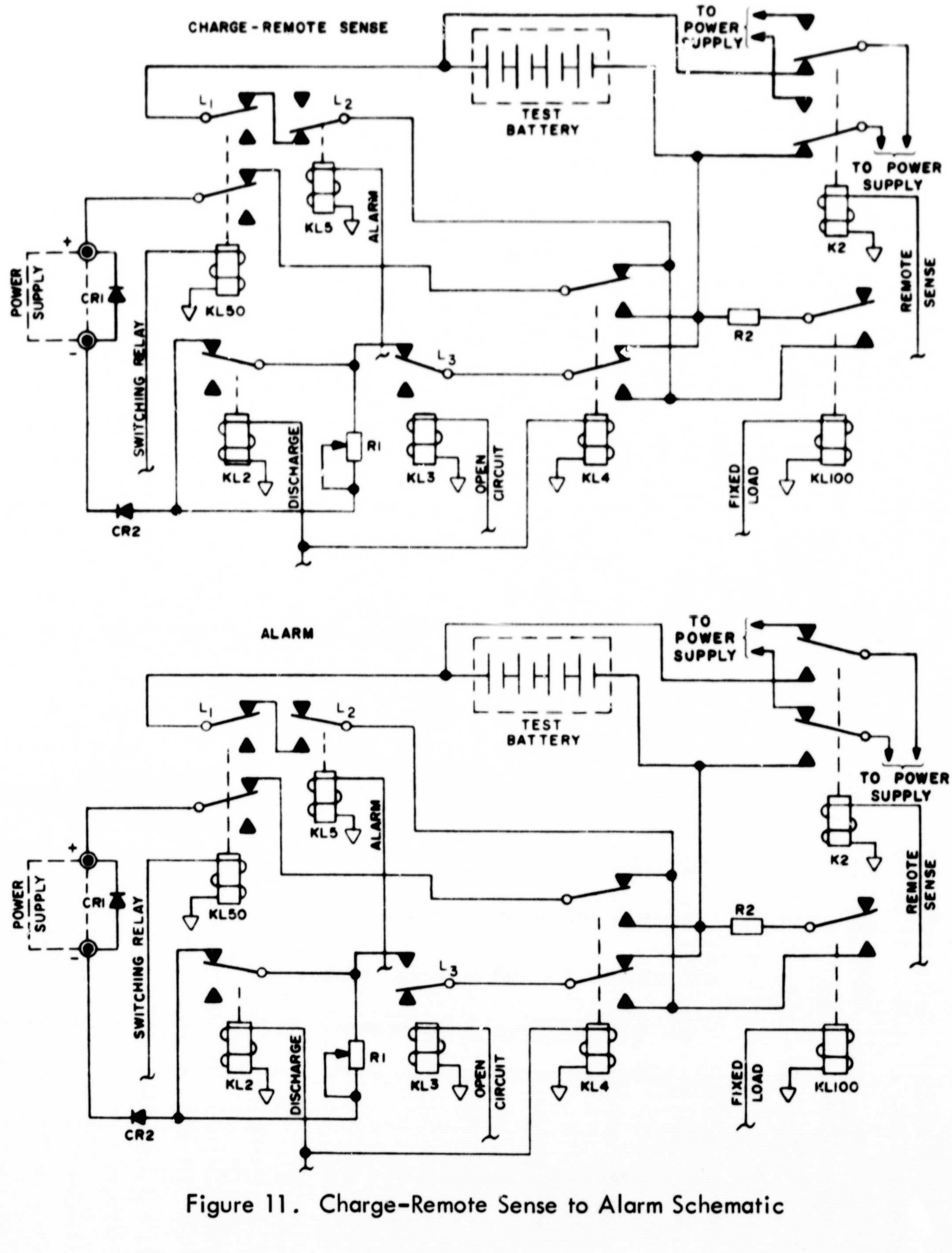
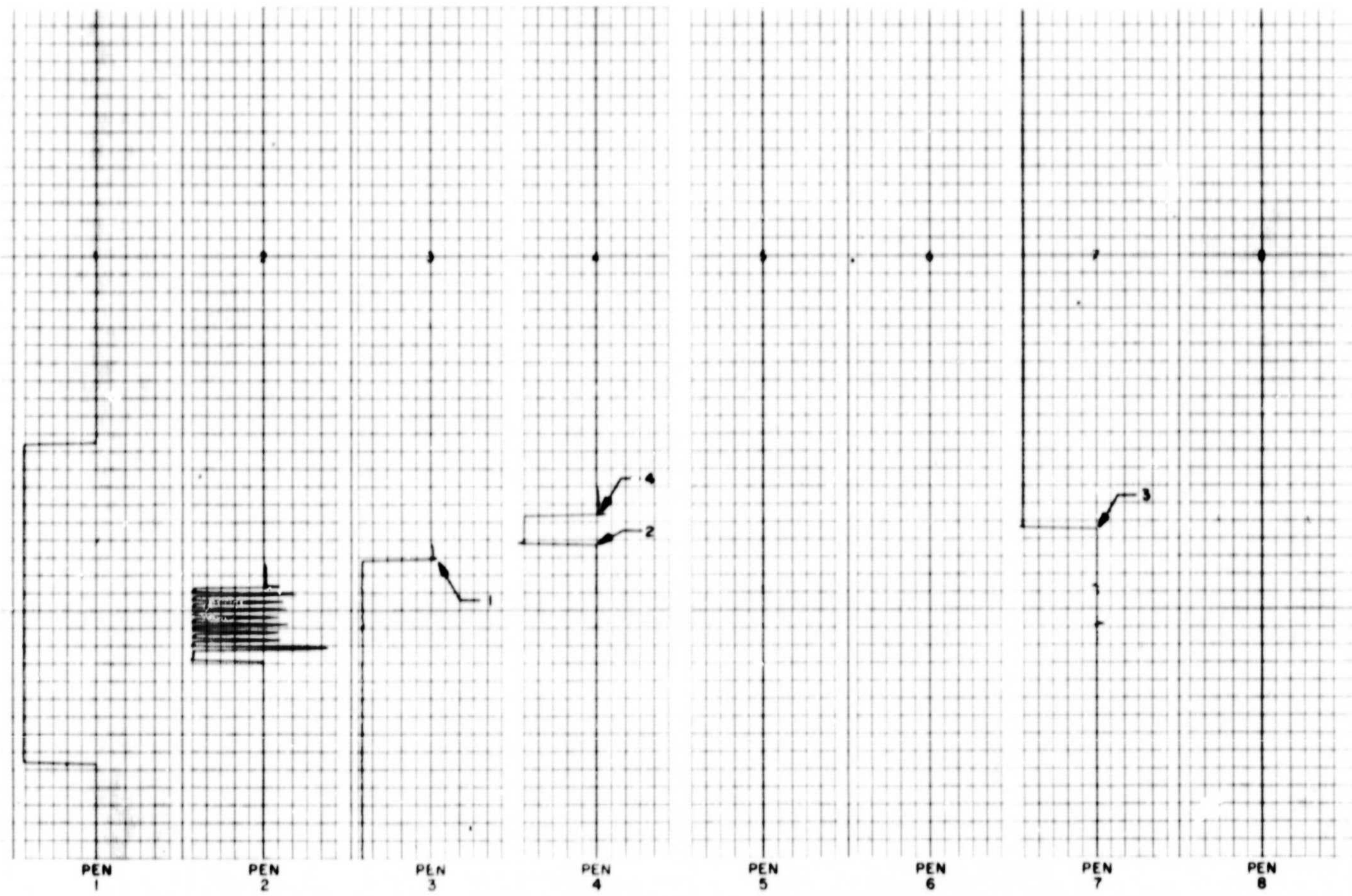


Figure 11. Charge-Remote Sense to Alarm Schematic



Arrow	Operation
1	Remote-sense lines switched from test battery to the power-supply output terminals
2	Positive load line L_1 disconnected
3	Negative load line L_3 disconnected
4	Positive load line L_1 connected

Figure 12. Charge-Remote Sense to Open Circuit Chart

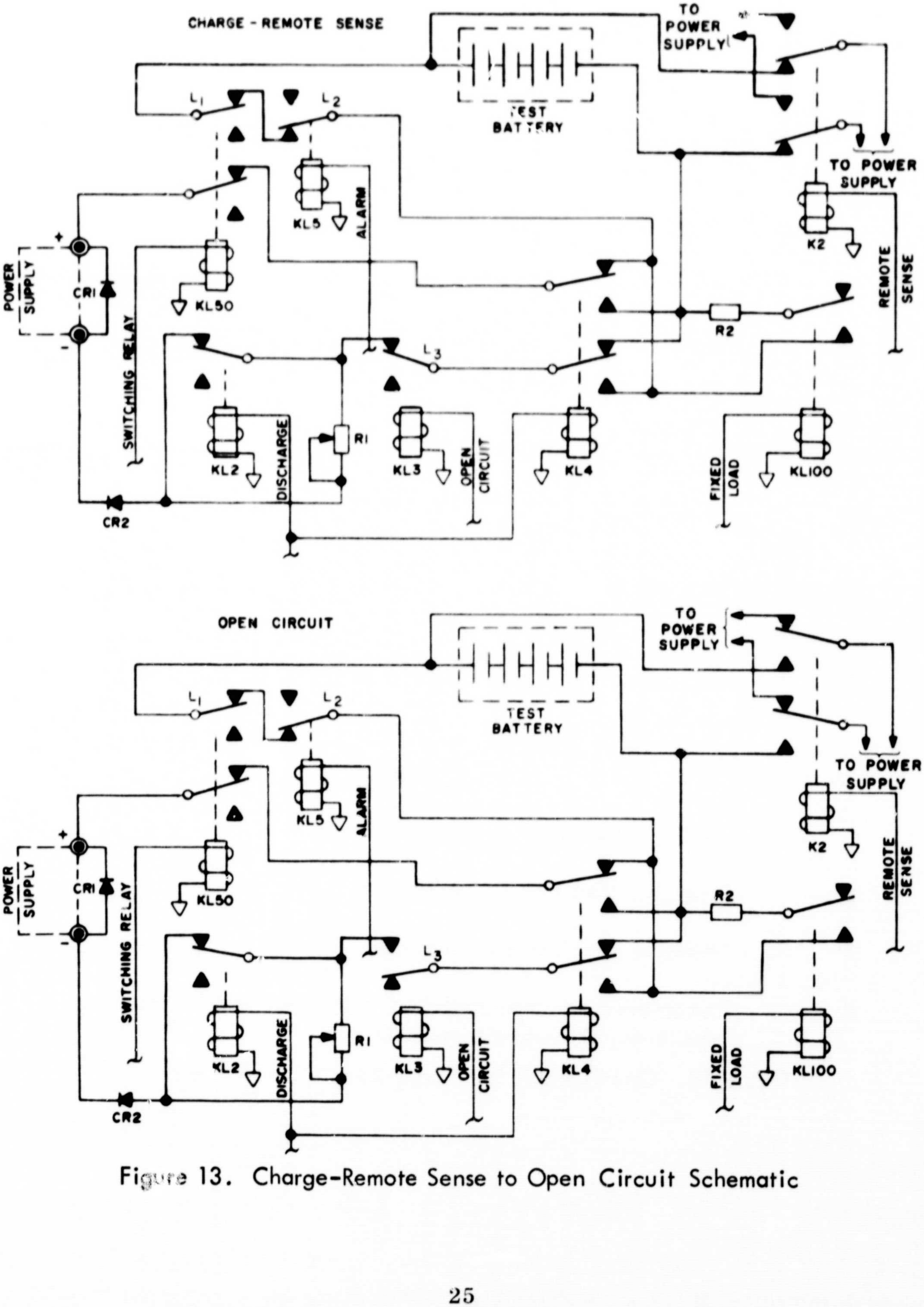
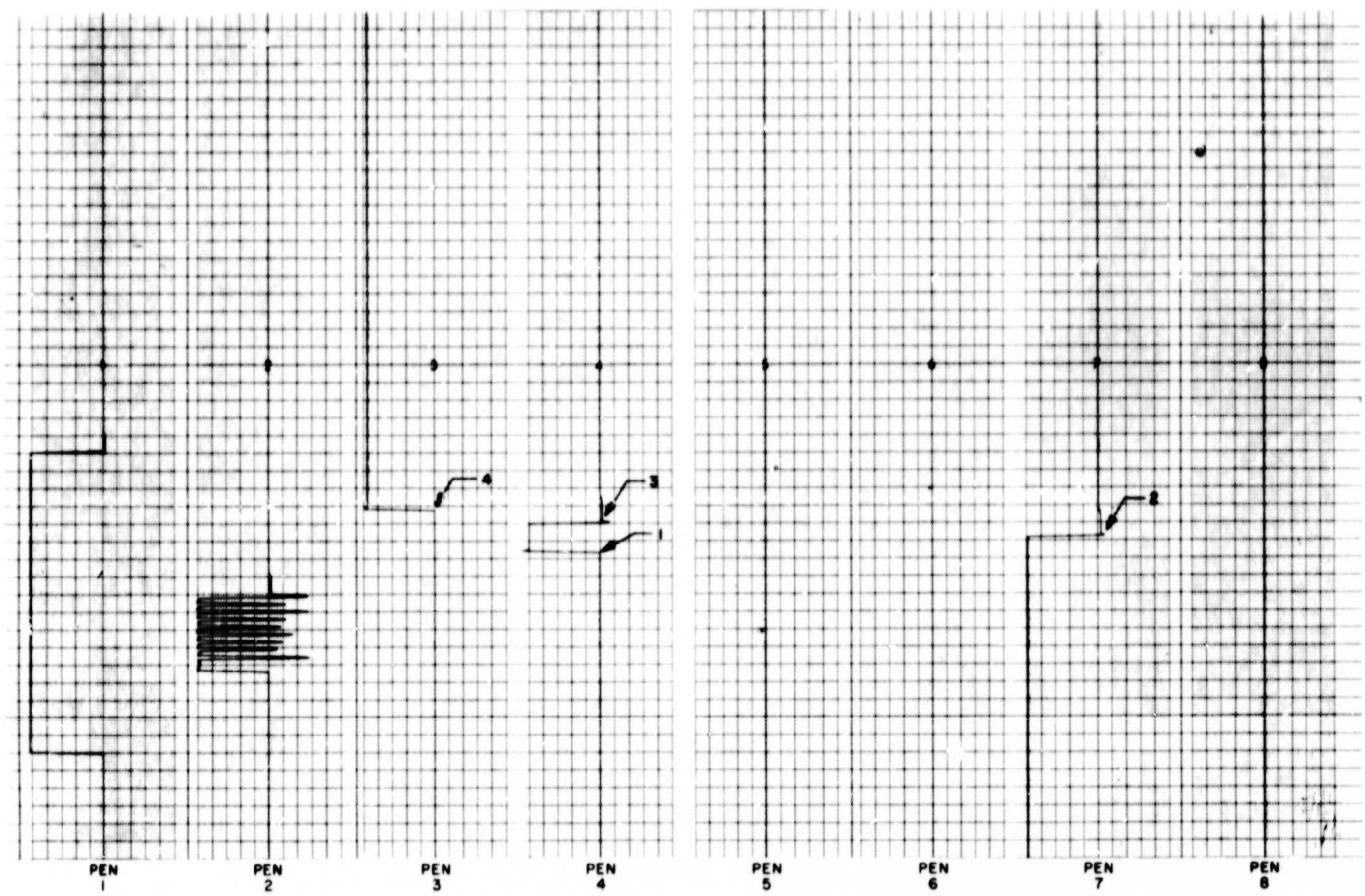


Figure 13. Charge-Remote Sense to Open Circuit Schematic



Arrow	Operation
1	Positive load line L_1 disconnected
2	Negative load line L_3 connected
3	Positive load line L_1 connected
4	Remote-sense lines switched to the test battery from the power-supply output terminals

Figure 14. Open Circuit to Charge-Remote Sense Chart

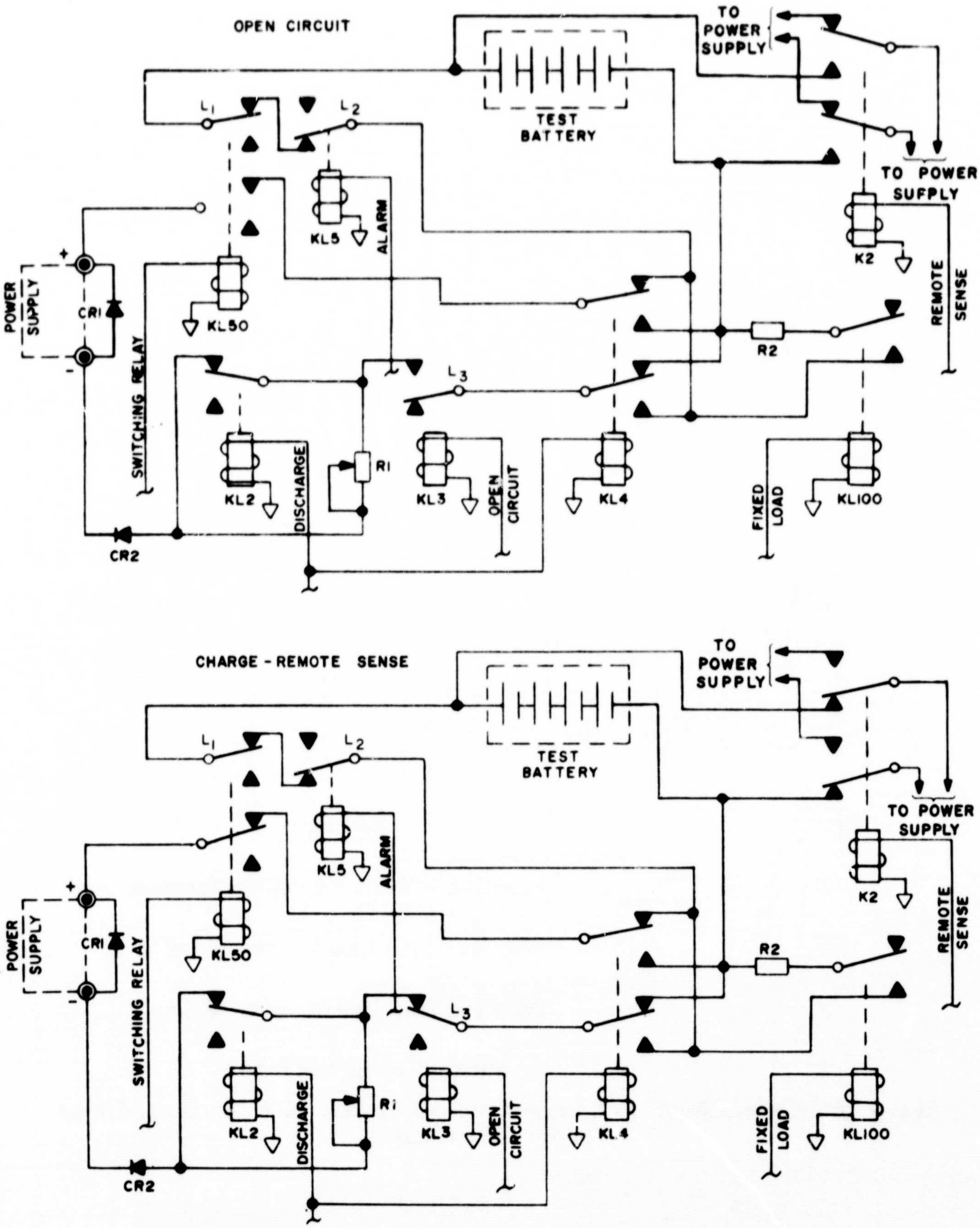
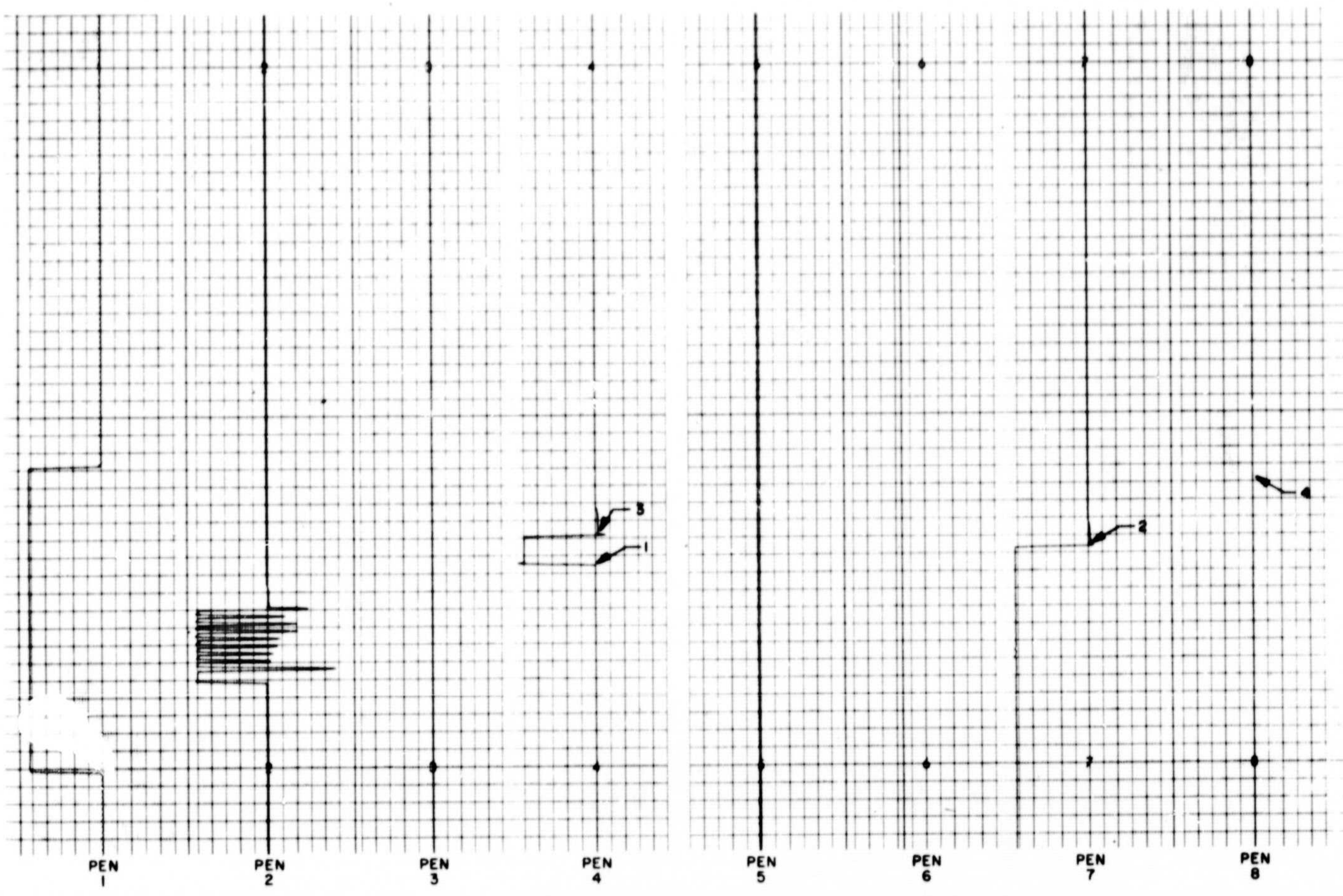
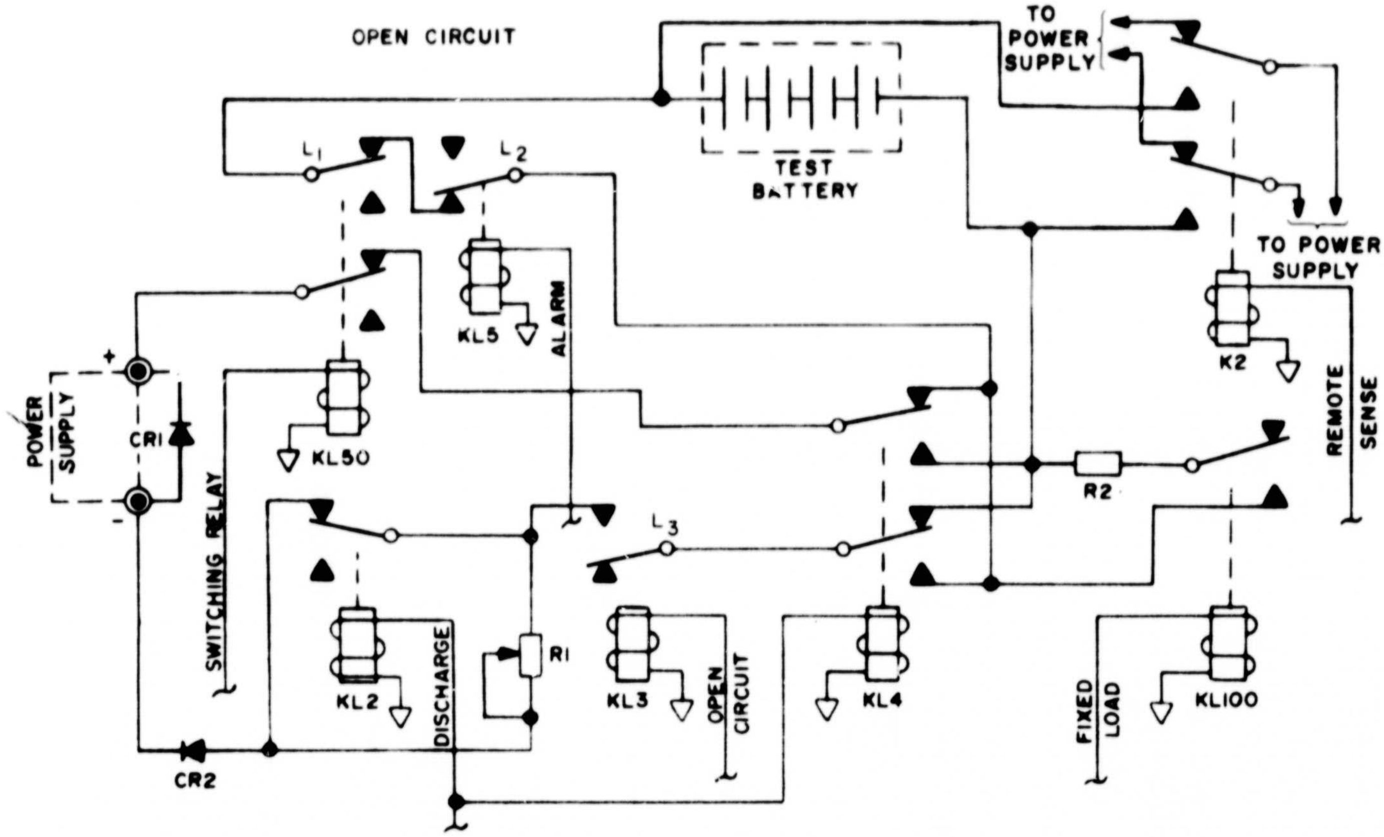


Figure 15. Open Circuit to Charge-Remote Sense Schematic



Arrow	Operation
1	Positive load line L_1 disconnected
2	Negative load line L_3 connected
3	Positive load line L_1 connected
4	No current spike recorded

Figure 16. Open Circuit to Charge-Constant Current, CR 2 In Line, Power Supply Off, Chart



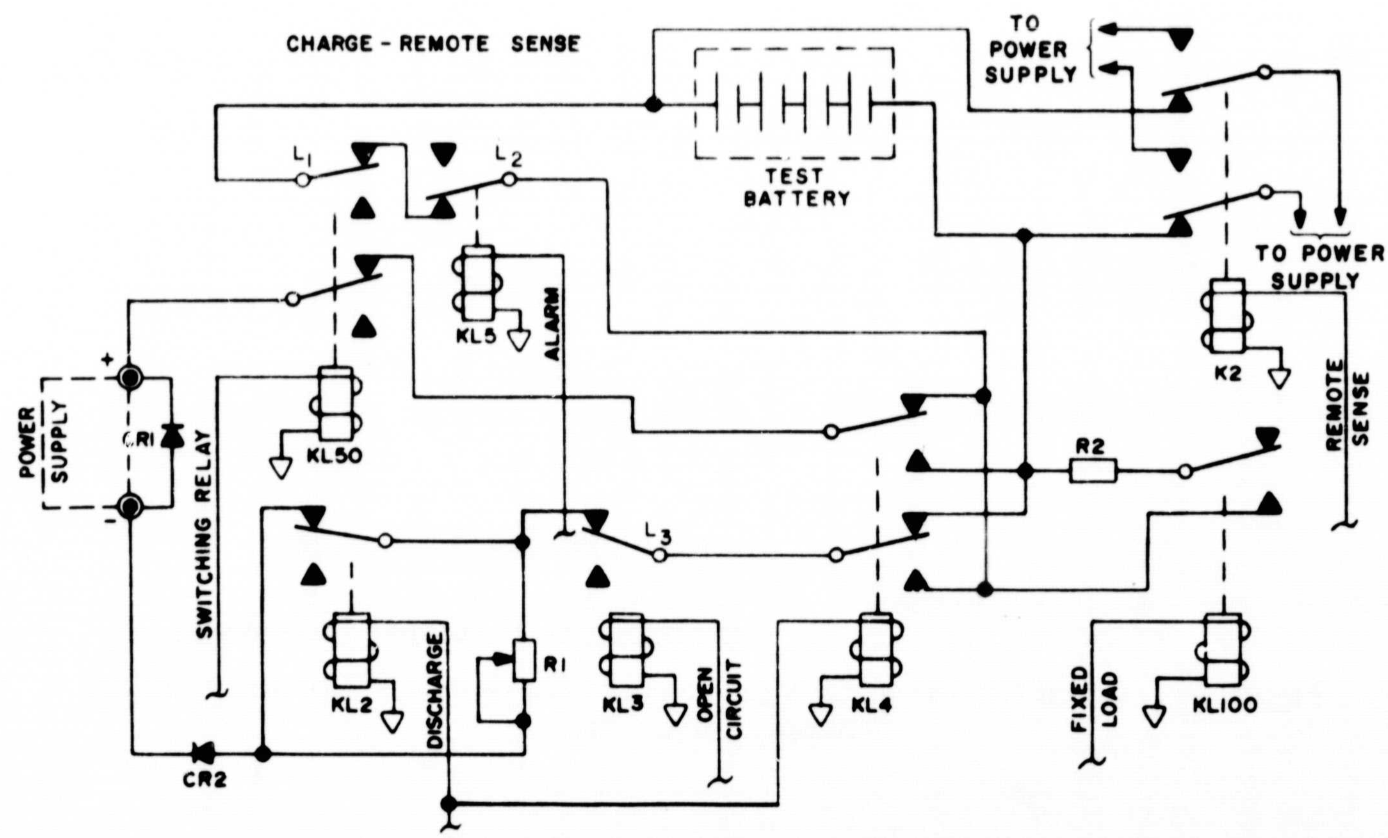
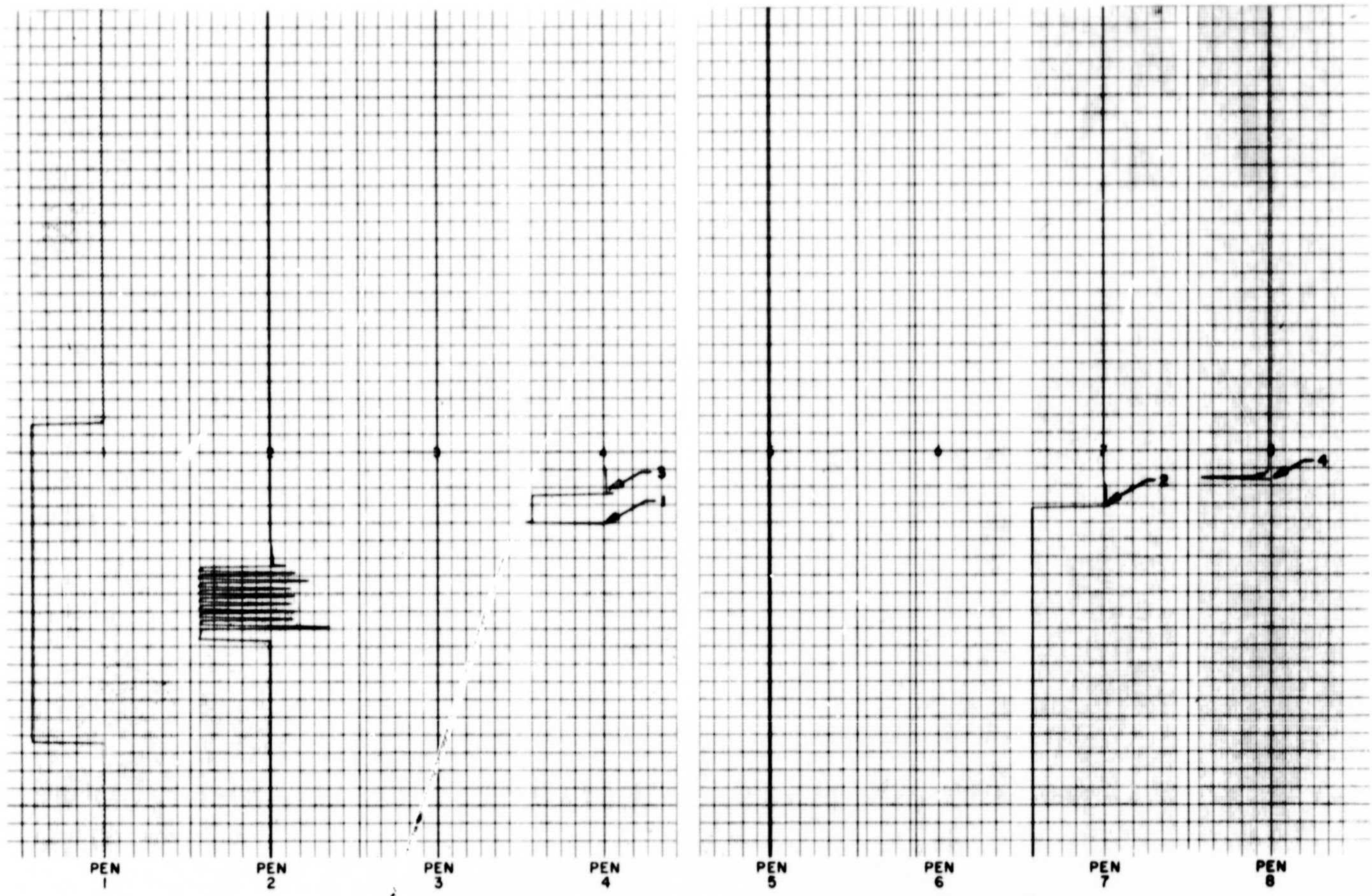
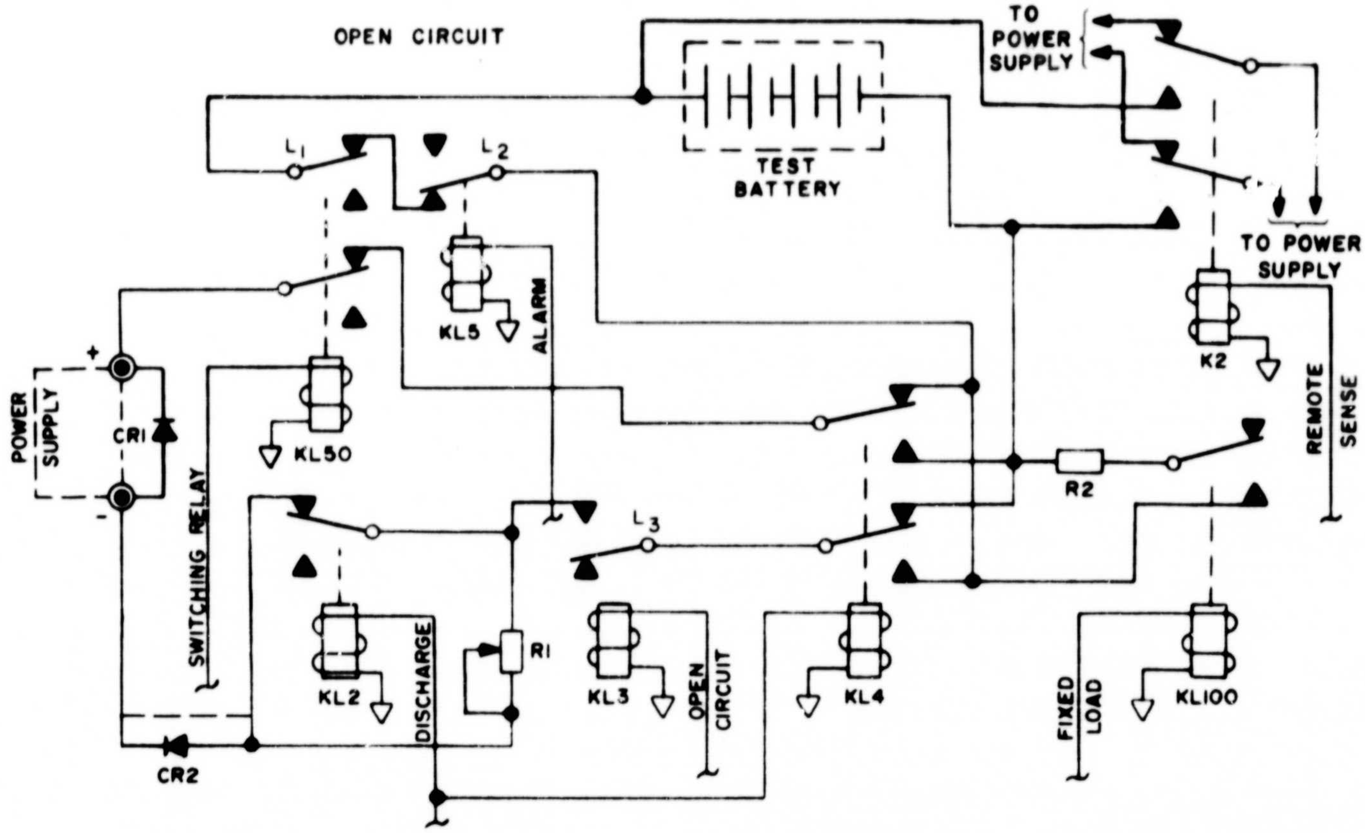


Figure 17. Open Circuit to Charge-Constant Current, CR 2 In Line, Power Supply Off, Schematic



Arrow	Operation
1	Positive load line L_1 disconnected
2	Negative load line L_3 connected
3	Positive load line L_1 connected
4	Current spike (25 amps) recorded

Figure 18. Open Circuit to Charge-Constant Current, CR 2 Shorted, Power Supply Off, Chart



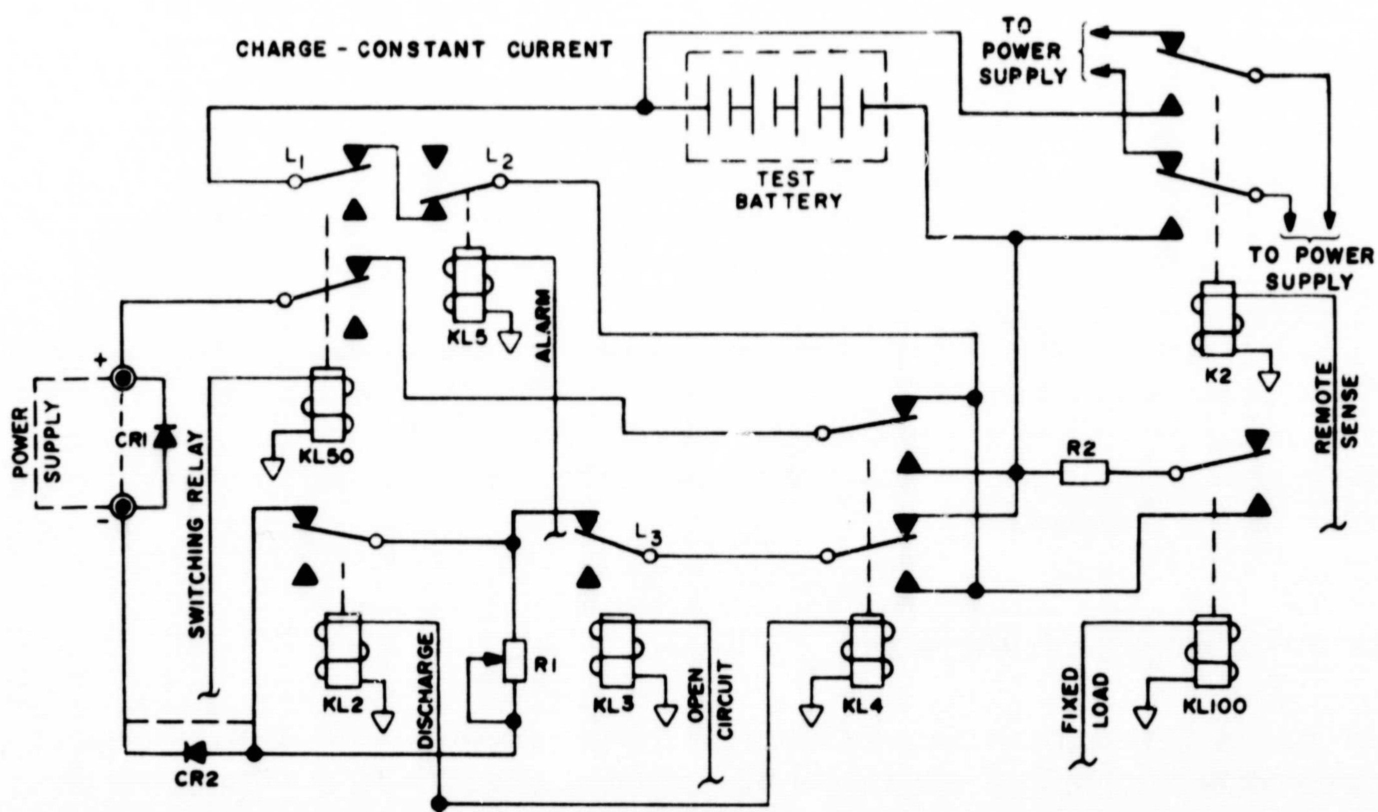


Figure 19. Open Circuit to Charge-Constant Current, CR 2 Shorted, Power Supply Off, Schematic

output terminal. This modification increases the specified IR drop to approximately 1.2 volts; therefore, caution is advised when using this procedure with battery-type loads programmed to the remote-sense mode. Using 1.320 volts when calculating, the static-state voltage of a partially or fully charged cell allows a 0.16-volt differential between a static-cell voltage (1.320 volts) and a possible 1.480-volt (ambient-upper voltage limit) remote-sense limit. Multiplying the differential by five (5 X 0.16 = 0.8 volt) produces a voltage drop which exceeds the required 0.7-volt breakdown limit of CR 2.

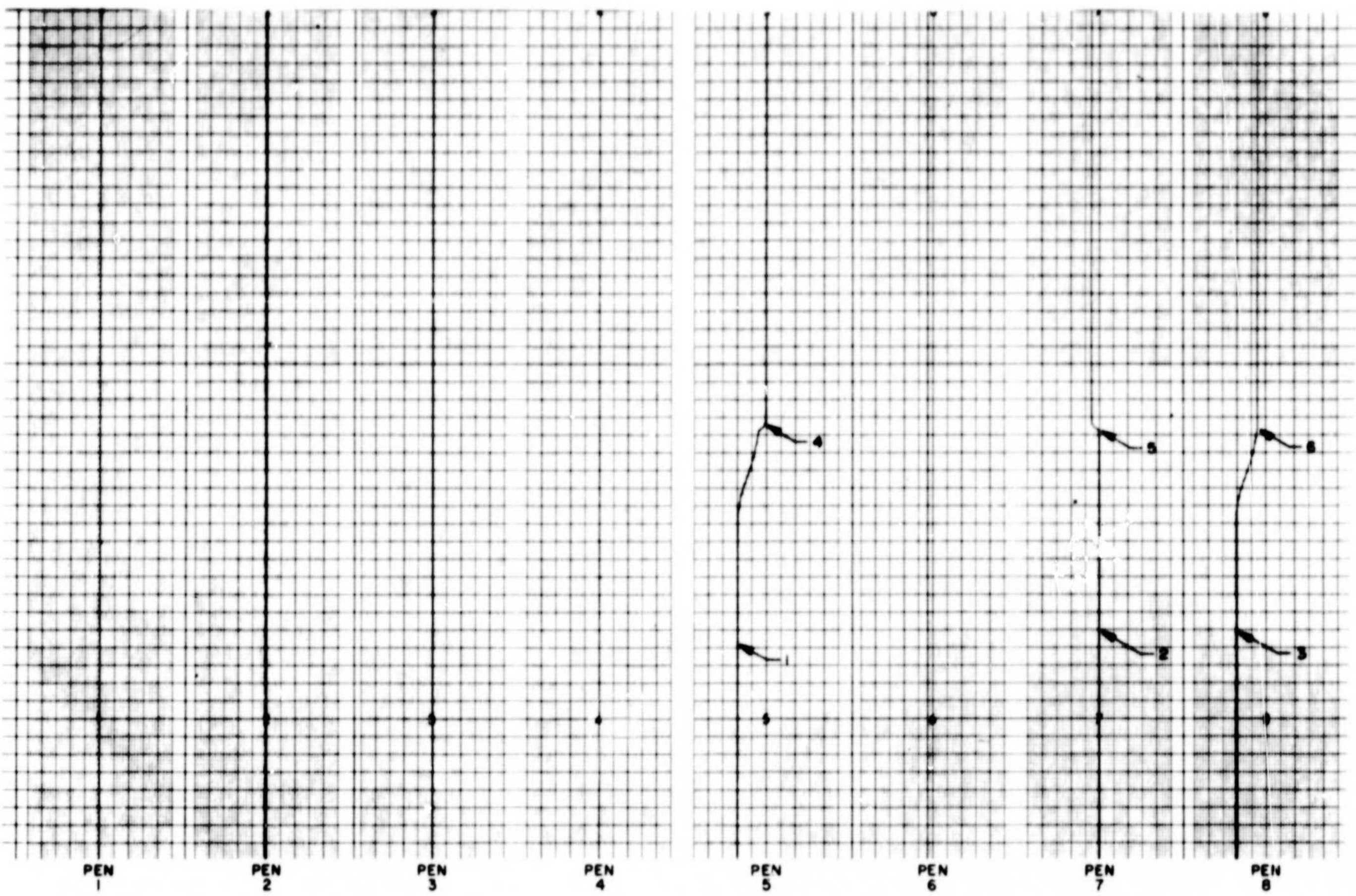
Reverse Current—Two power supplies connected in series across a common load require a pair of diodes connected inversely across each supply for protection against a reverse potential during an ac failure (potential loss), etc. (Each diode provides an external path for the load current around the supply.) Also, discharging a regulated supply battery requires reverse-diode protection for the power supply and monitoring control of the battery output. Figures 20 and 21 show how protection is provided by using reverse diode CR 1 shown in Figure 21. The harmful current path through the static-power supply (Figure 22) is shown (arrow 4 of Figure 23) switched to the external diode path (arrow 5 of Figure 20).

Current Surges—The response time of the power supplies in the microsecond region exceeds the normal switching time specified by relay manufacturers. These conditions generate large inrush-current spikes during load-switching transition unless the cycler is designed to suppress spikes. This surge can be virtually eliminated by programming the supply current to 5 percent of rated current during the mode-switching time shown in Figure 24 and by arrow 5 of Figure 25. Arrow 5 of Figure 27 shows this kind of a spike. Switching from a 5-amp discharge mode to a 5-amp charge mode (Figure 26) generates a current spike of approximately 20 amps, with no provisions for current suppression.

No differential current-level rates were noted when the test battery was switched from a charge to a discharge mode (Figures 28, 29, 30, and 31). The response time of the power supply provides instant regulation for the battery load current; the regulation provides a method of current suppression during transition before the load line is closed.

FUTURE DESIGN CONCEPTS

Several cycler characteristics should be analyzed before future battery cyclers are designed. The next model will be evaluated using the external support of a processor-oriented control system with provisions to select local-input control. This method implements design revisions to isolated modular sections, independent of the remaining sections of a battery cycler. Figure 32 shows one of the first steps using this approach, which starts the modular breakdown. To design



Arrow	Operation
Power Supply On	
1	Power-supply output current at 5.0 amps
2	CR-1 current at 0.0 amp (shunt 1)
3	Load current at 5.0 amps (shunt 2)
Power Supply Off	
4	Power-supply output current at 0.0 amp
5	CR-1 current at 1.5 amps (shunt 1)
6	Load current at 1.5 amps (shunt 2)

Figure 20. Discharge-Constant Current, CR 1 Across Power-Supply Output Terminals, Chart

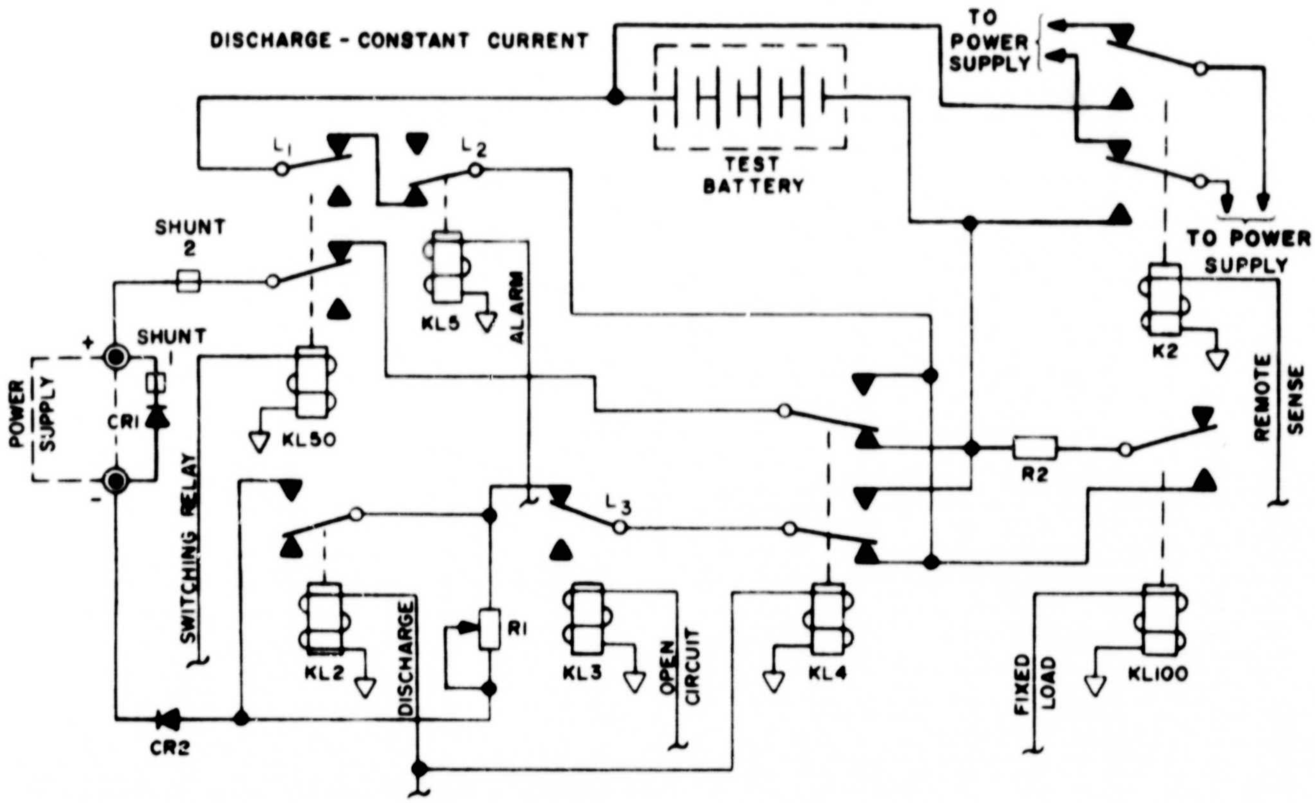


Figure 21. Discharge-Constant Current, CR 1 Across Power-Supply Output Terminals, Schematic

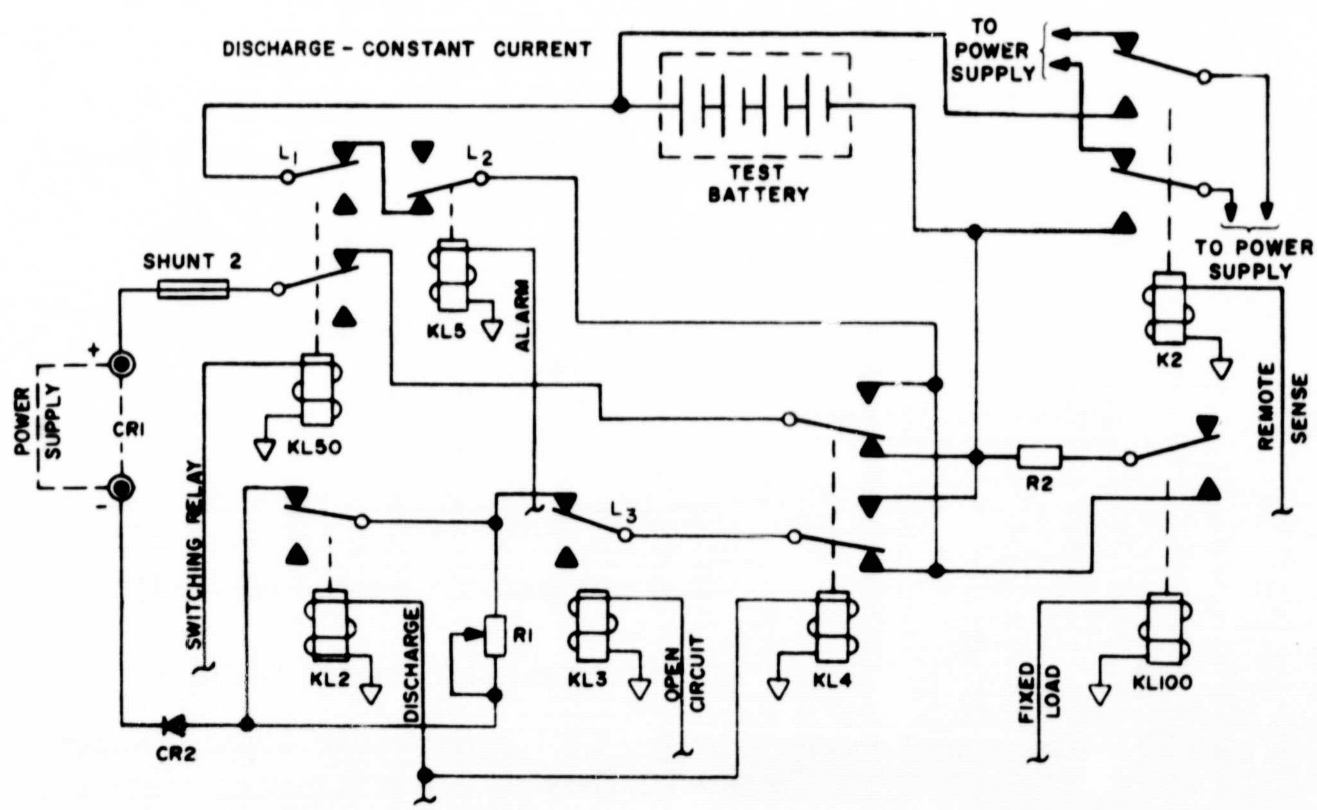
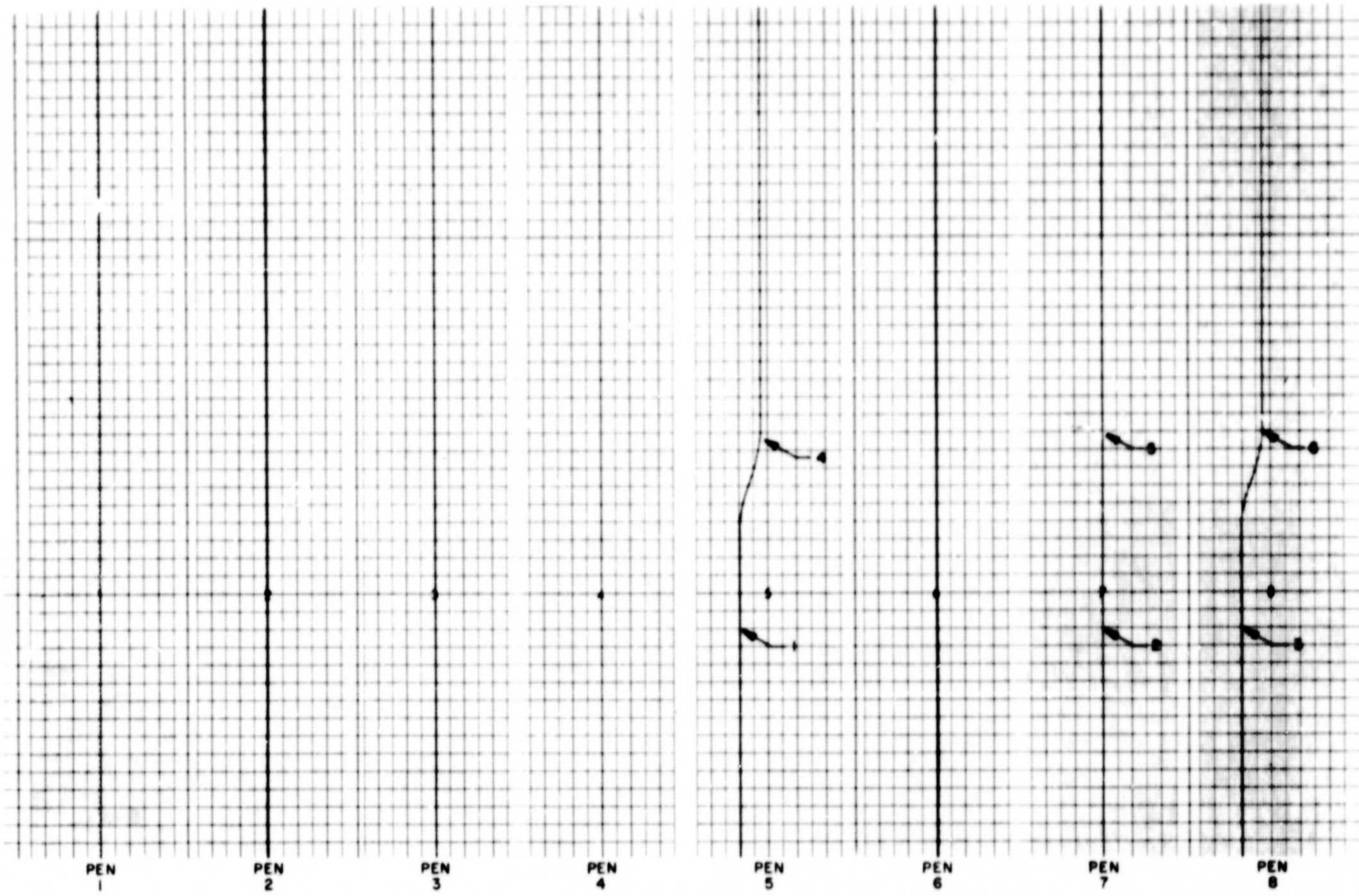


Figure 22. Discharge-Constant Current With CR 1 Removed From the Power-Supply Output Terminals, Schematic



Arrow	Operation
Power Supply On	
1	Power-supply current at 5.0 amps
2	Diode CR 1, out of circuit
3	Load current at 5.0 amps
Power Supply Off	
4	Power-supply current at 1.5 amps
5	Diode CR 1, out of circuit
6	Load current at 1.5 amps

Figure 23. Discharge-Constant Current With CR 1 Removed From the Power-Supply Output Terminals, Chart

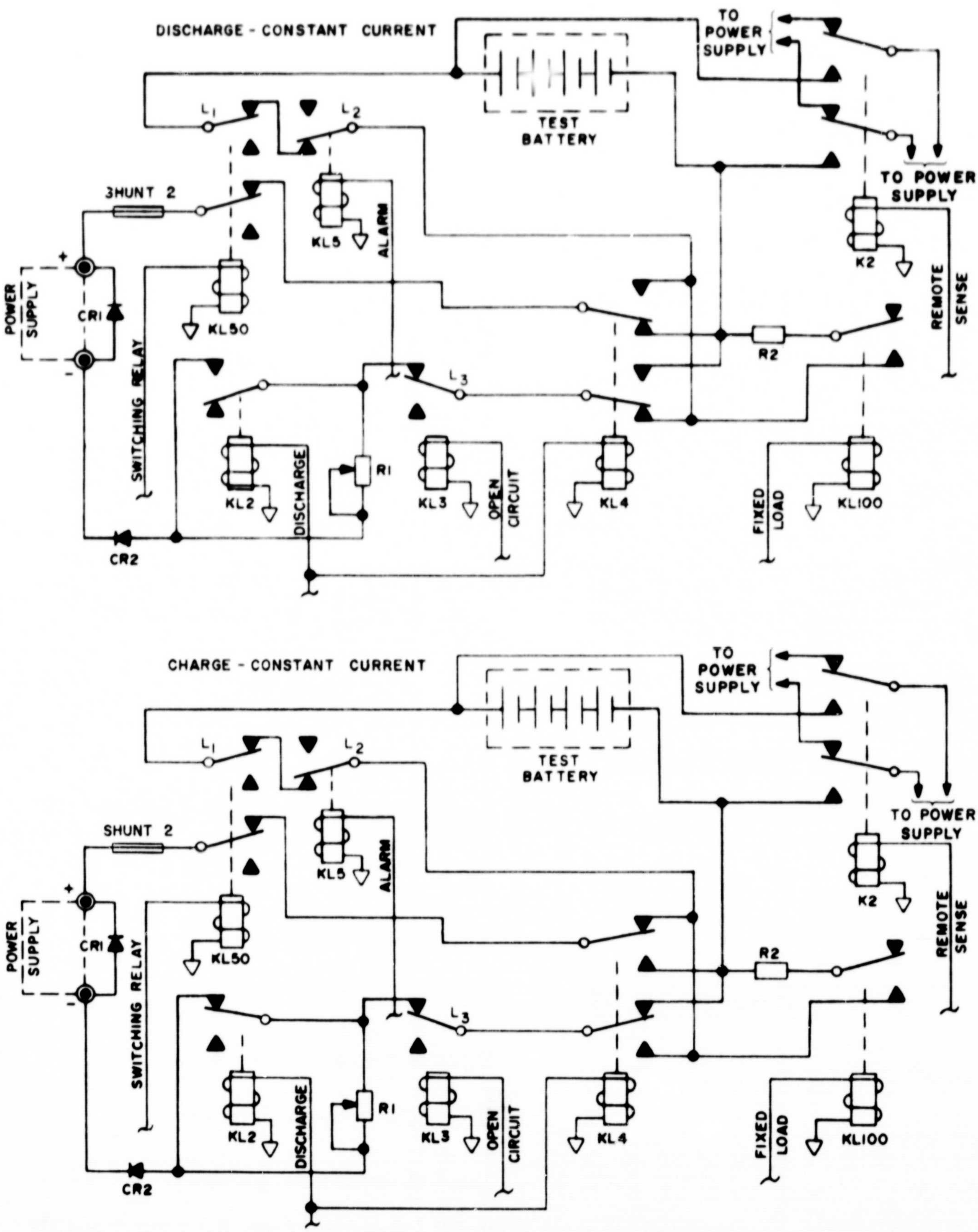
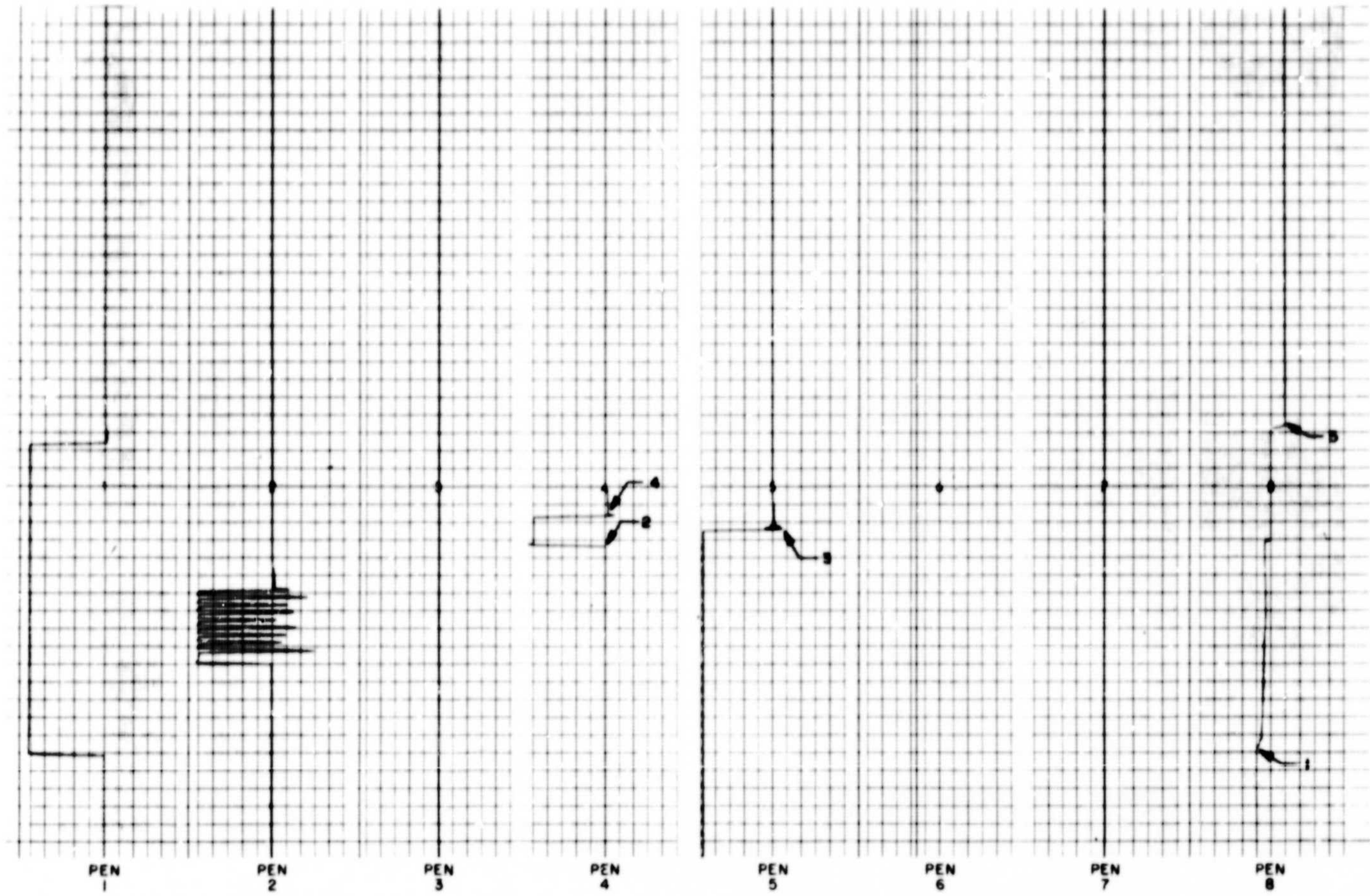


Figure 24. Discharge–Constant Current to Charge–Constant Current With Power–Supply Output Suppressed During Switching, Schematic



Arrow	Operation
1	Power-supply load current dropped from 5.0 to 2.5 amps during switching operations
2	Positive load line L_1 disconnected
3	Test battery switched from discharge to charge position
4	Positive load line L_1 connected
5	Power-supply current switched to 5.0 amps

Figure 25. Discharge-Constant Current to Charge-Constant Current With Power-Supply Output Suppressed During Switching, Chart

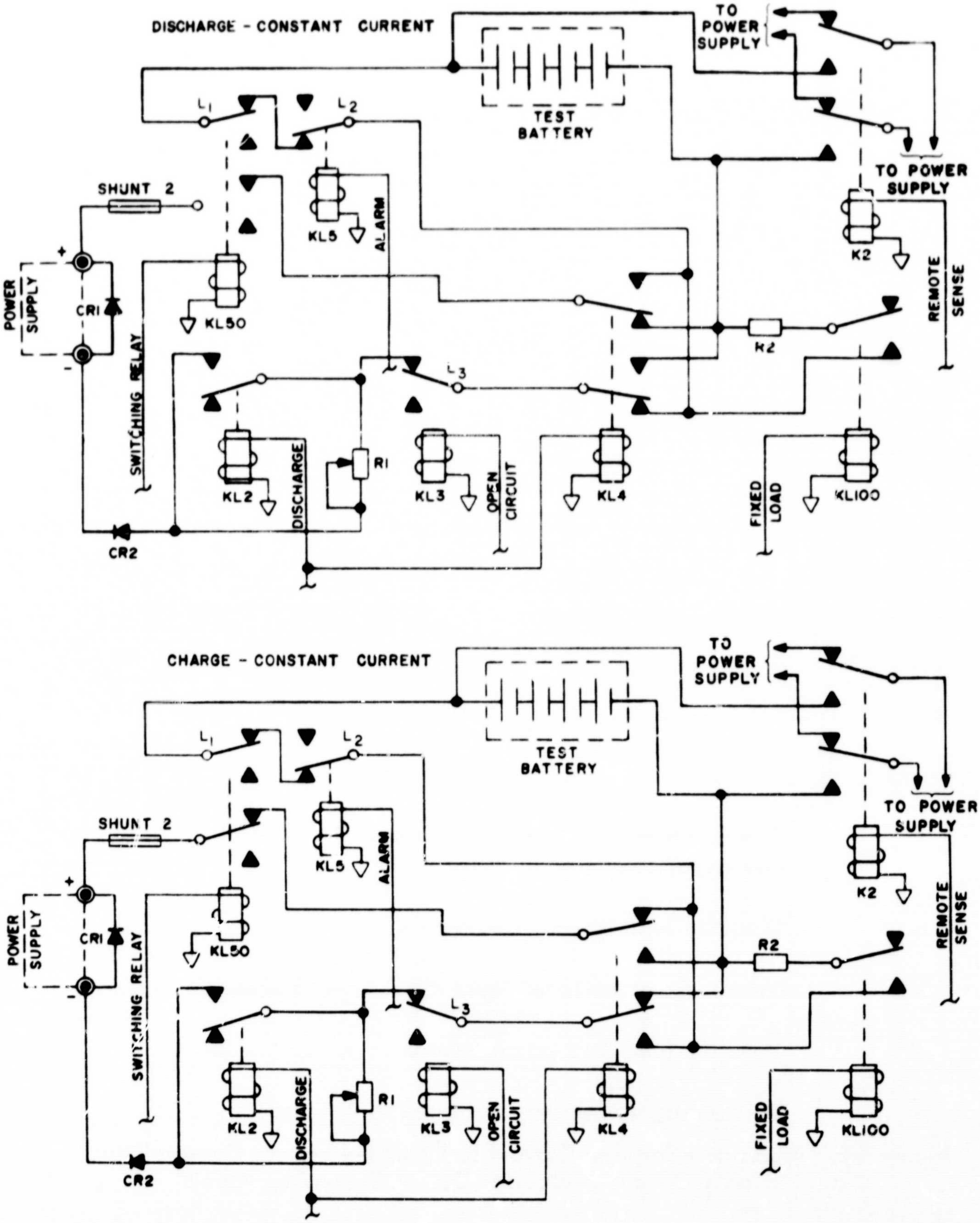
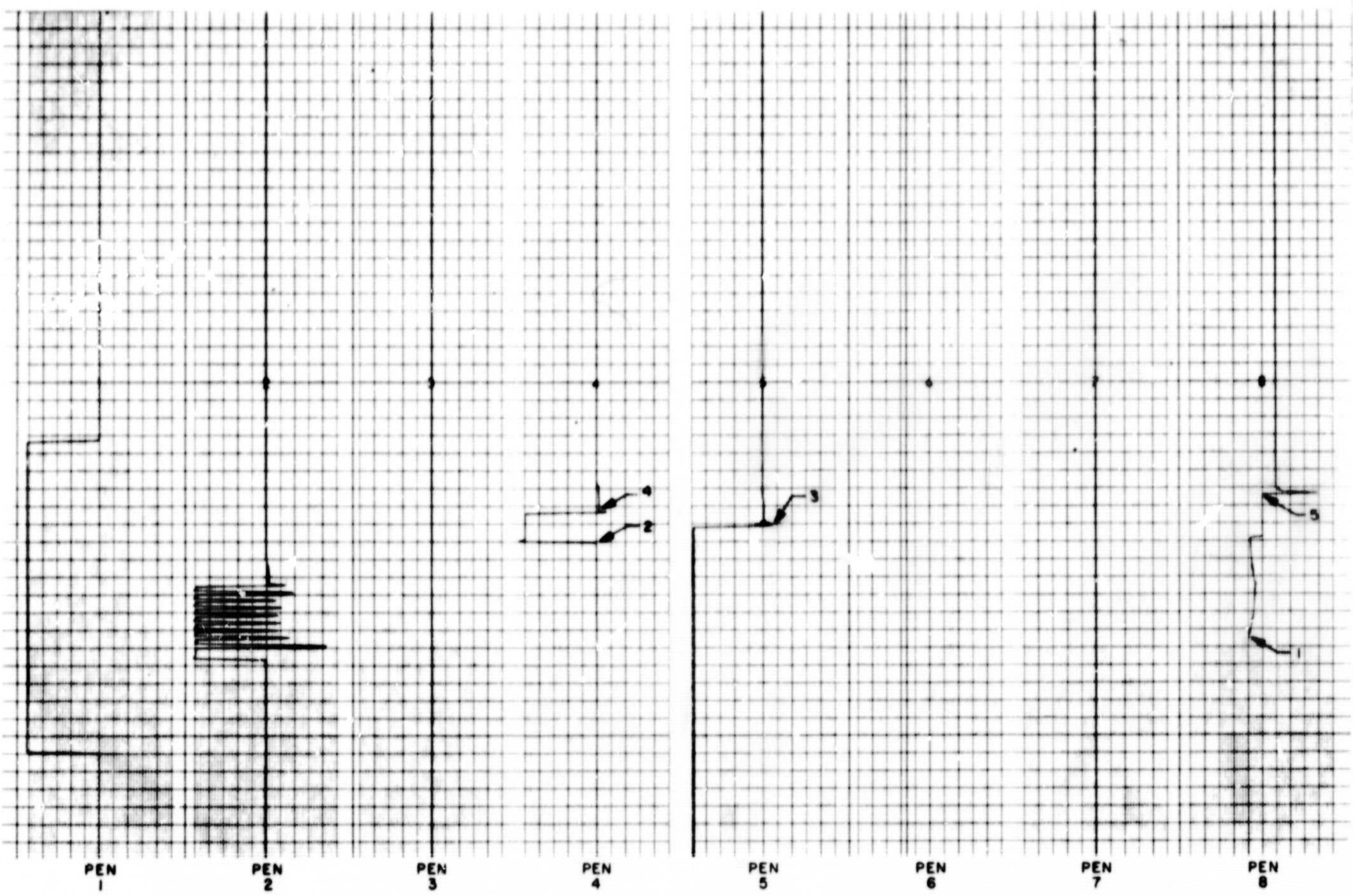


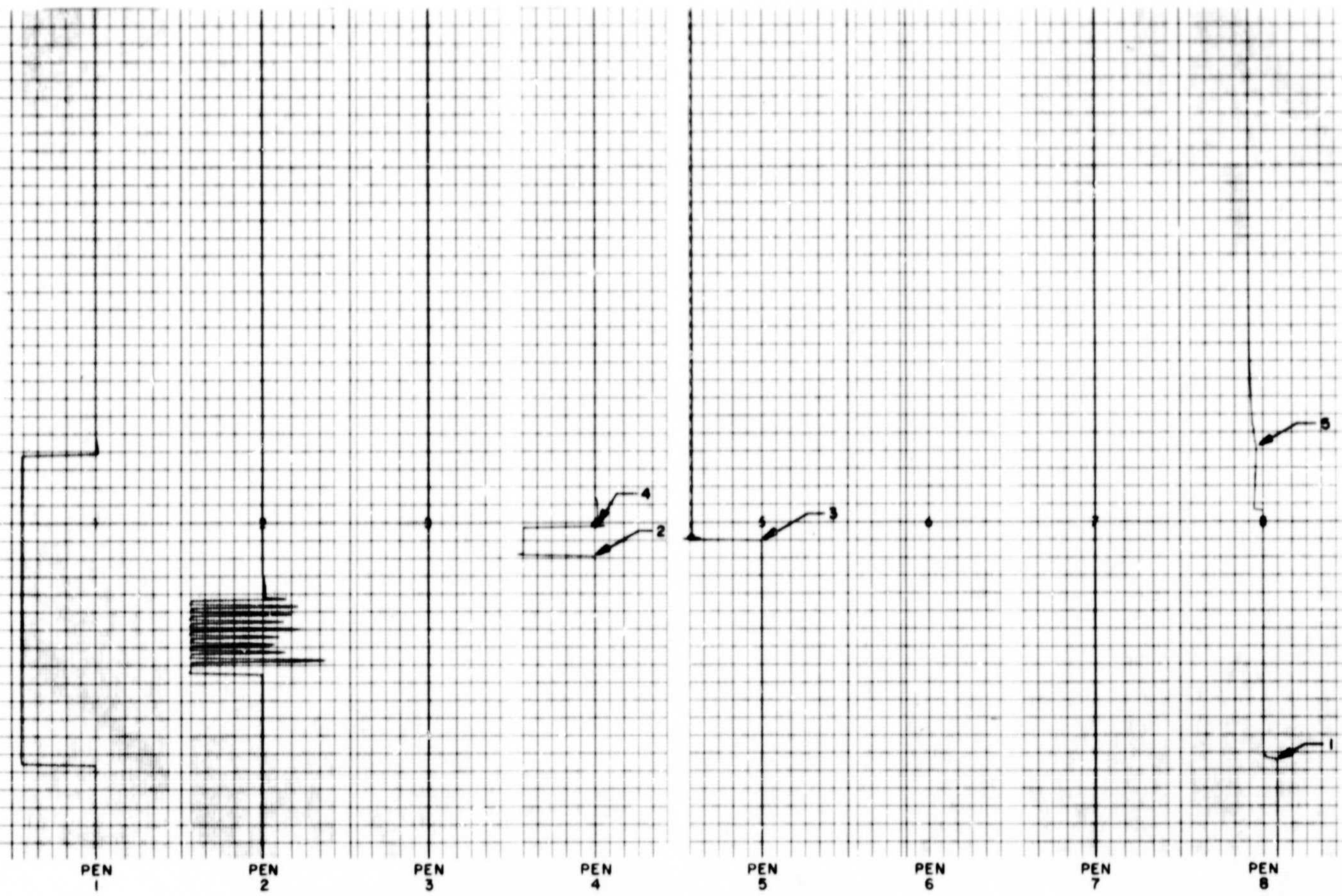
Figure 26. Discharge-Constant Current to Charge-Constant Current, Power-Supply Output Suppressed During Switching, Schematic



Arrow	Operation
1	Power-supply lowering current level
2	Positive load line L_1 disconnected
3	Test battery switched from discharge to charge position
4	Positive load line L_1 connected
5	A current spike (20 amps) recorded when power supply programmed from -5.0 to +5.0 amps in one step

Figure 27. Discharge-Constant Current to Charge-Constant Current, Power-Supply Output Suppressed During Switching, Chart*

*The current limit is set at 5.0 amps.



Arrow	Operation
1	Current control of the power supplies switched to a 2.5-amp level (50 percent below the required 5.0-amp level). Diode CR 2 carries load current through buffer resistor R 1.
2	Positive load line L_1 disconnected
3	Test battery switched from a charge to a discharge mode
4	Positive load line L_1 connected
5	Load current returned to a 5.0-amp level

Figure 28. Charge-Constant Current to Discharge-Constant Current With Power-Supply Output Suppressed During Switching, Chart

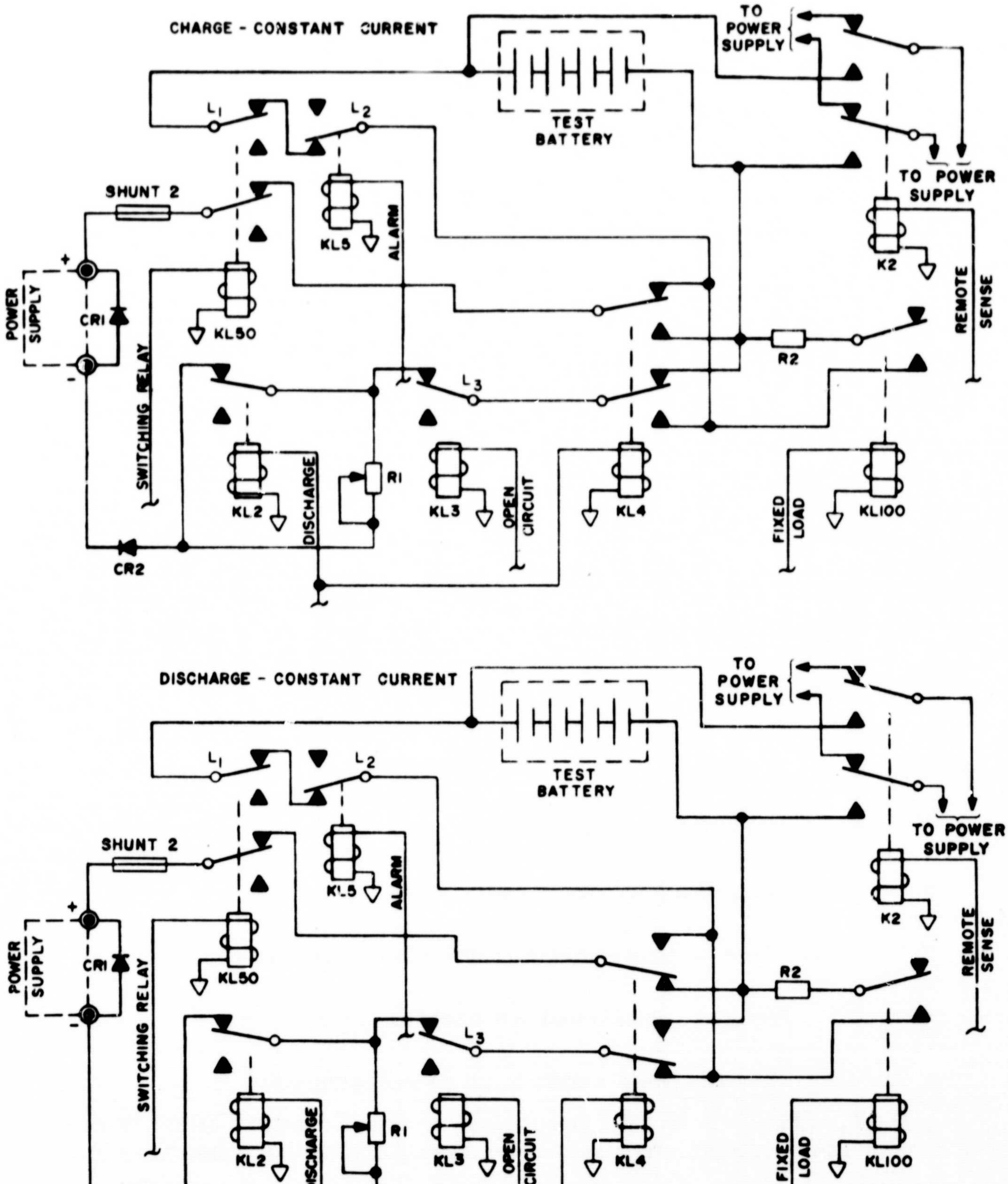
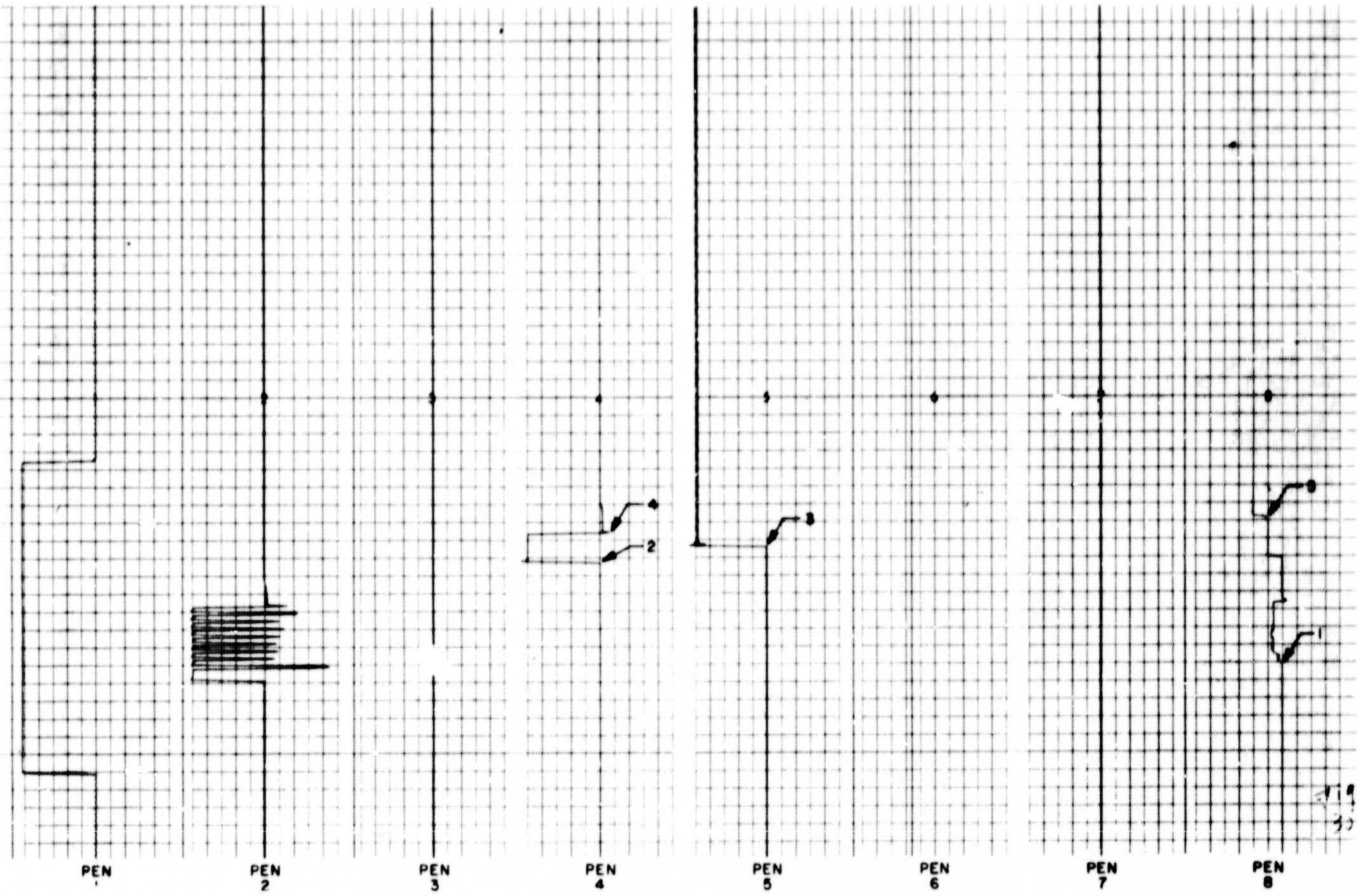


Figure 29. Charge-Constant Current to Discharge-Constant Current With Power-Supply Output Suppressed During Switching, Schematic



Arrow	Operation
1	Power-supply dropping current level
2	Positive load line L_1 disconnected
3	Test battery switched from charge to a discharge mode
4	Positive load line L_1 connected
5	Load current starts to go to 5.0-amp level

Figure 30. Charge-Constant Current to Discharge-Constant Current With Power-Supply Output Suppressed During Switching, Chart*

*The current limit is set at 5.0 amps.

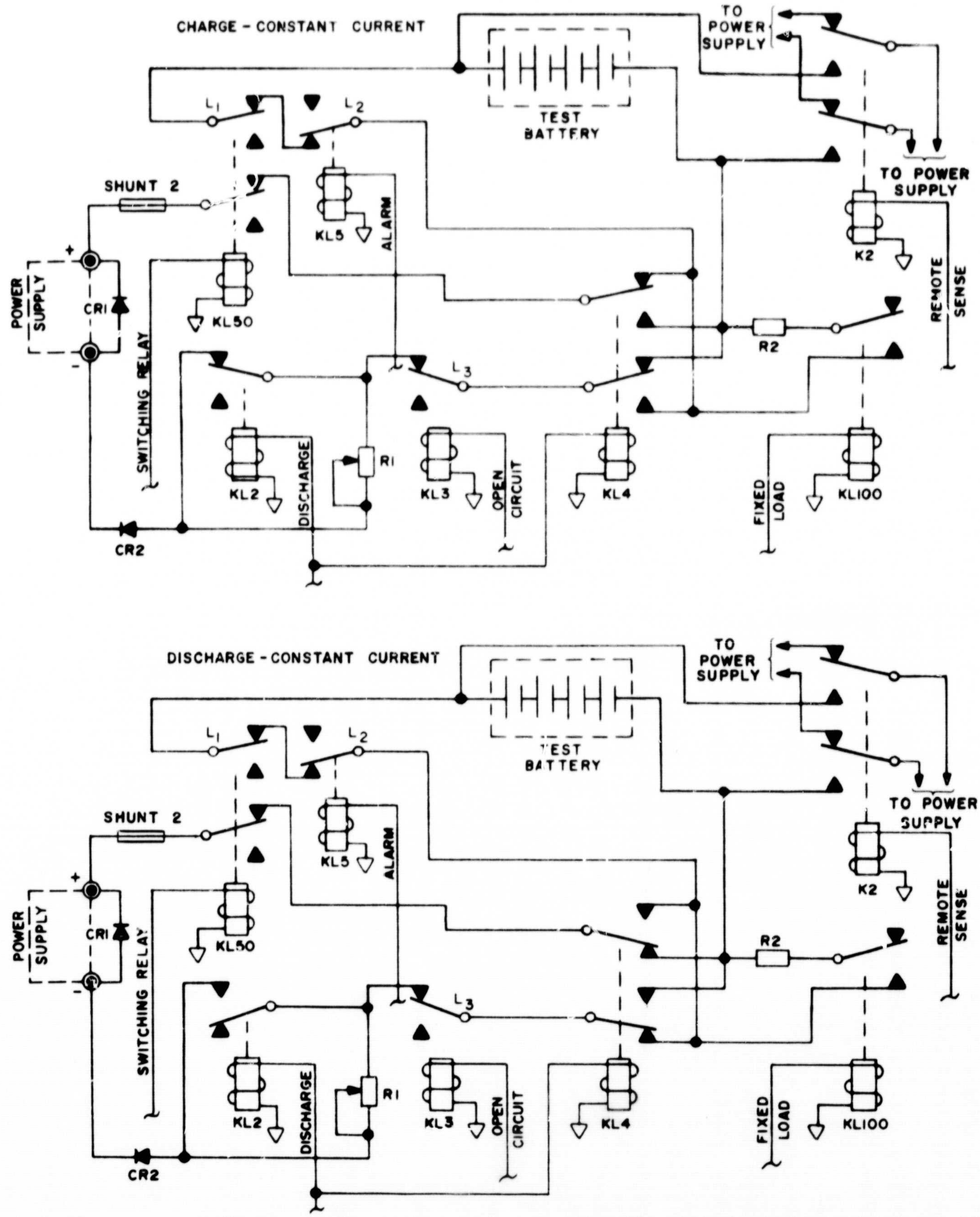
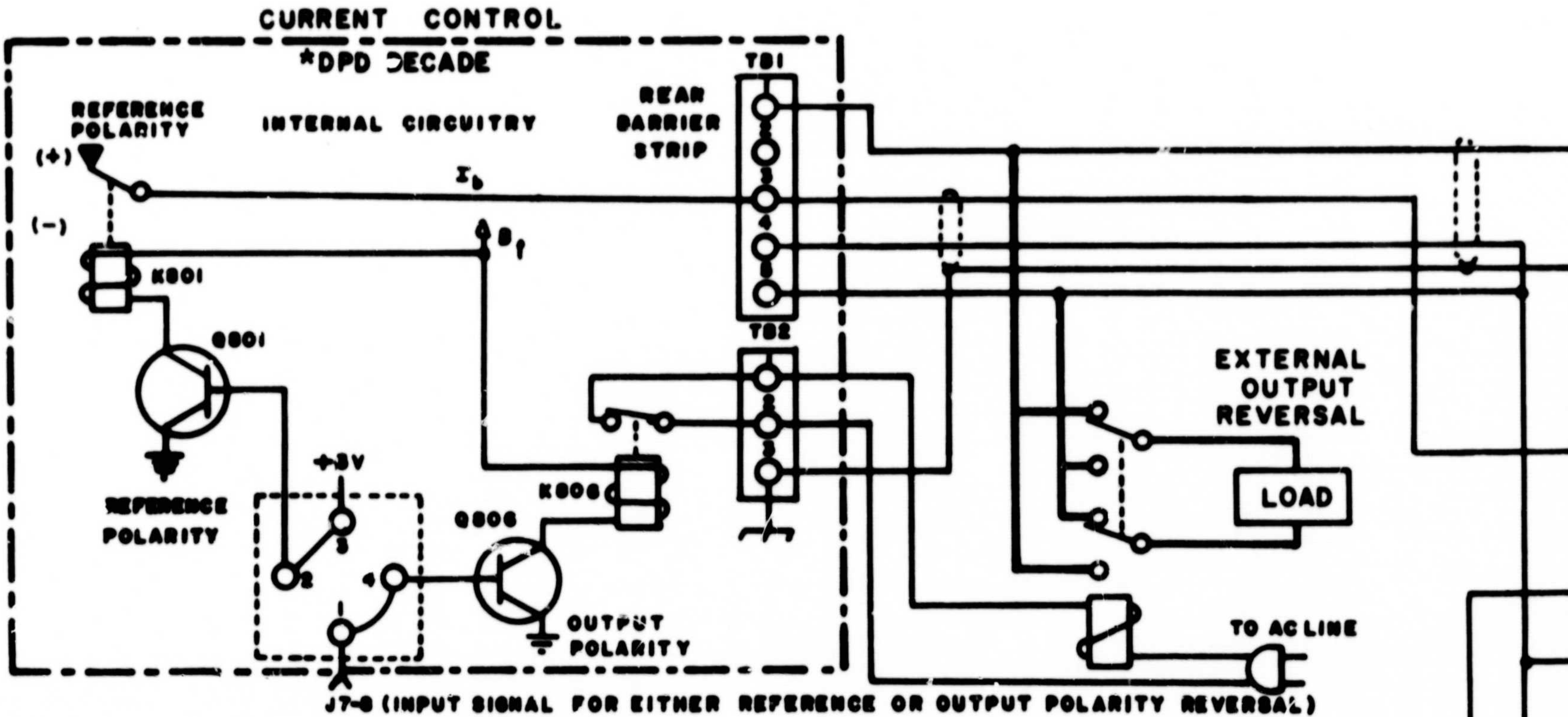
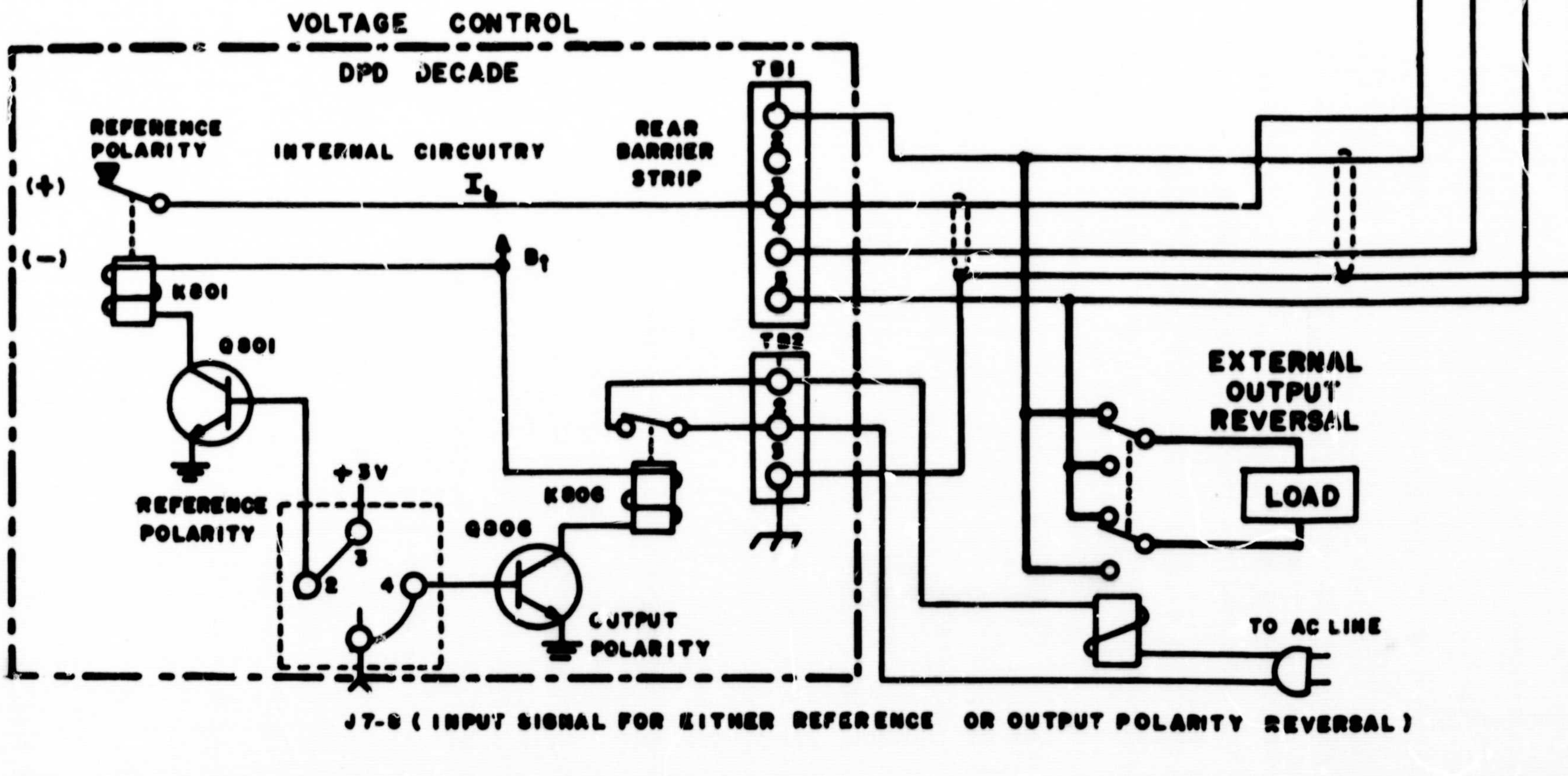
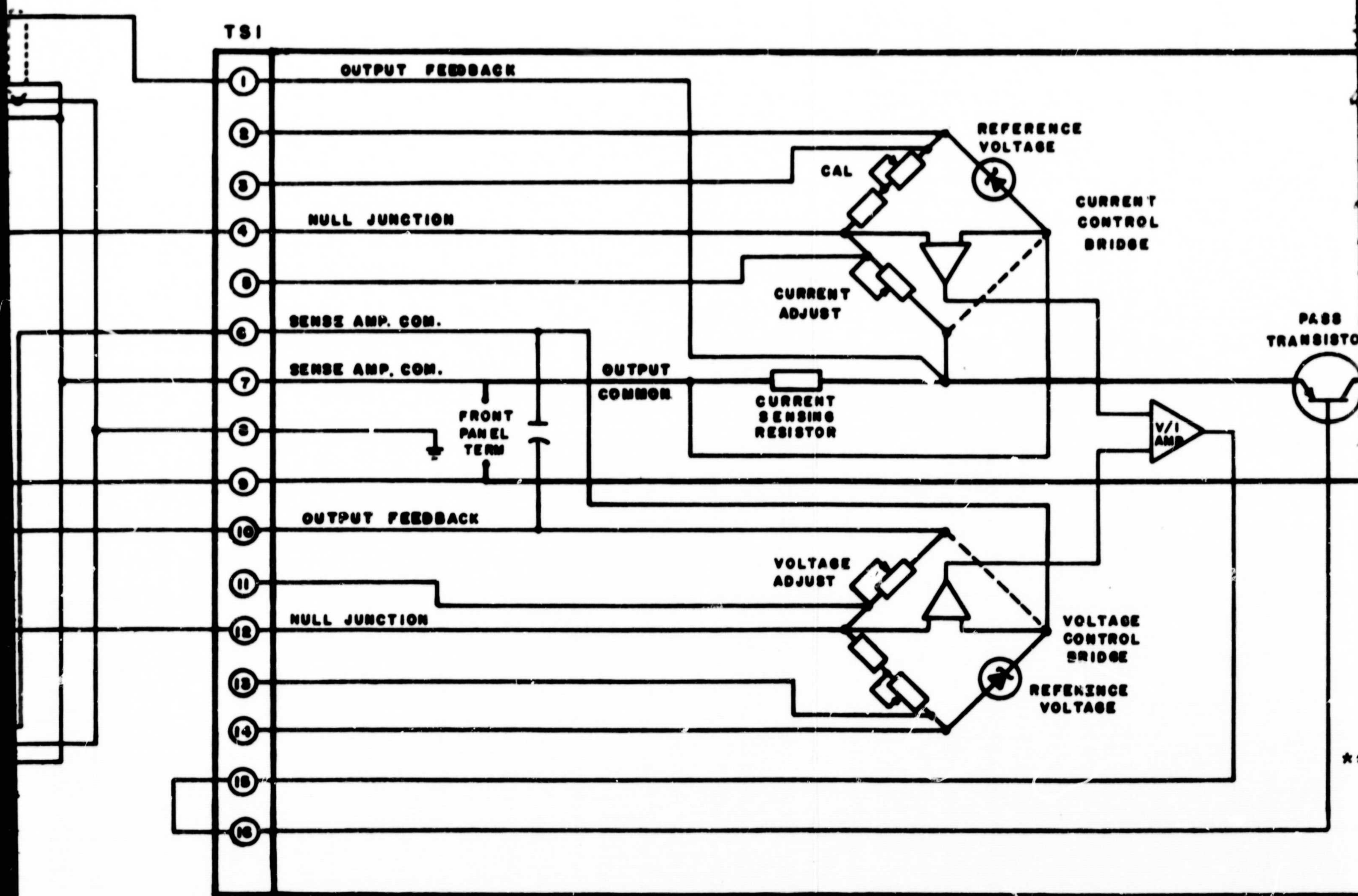


Figure 31. Charge-Constant Current to Discharge-Constant Current With Power-Supply Output Suppressed During Switching, Schematic





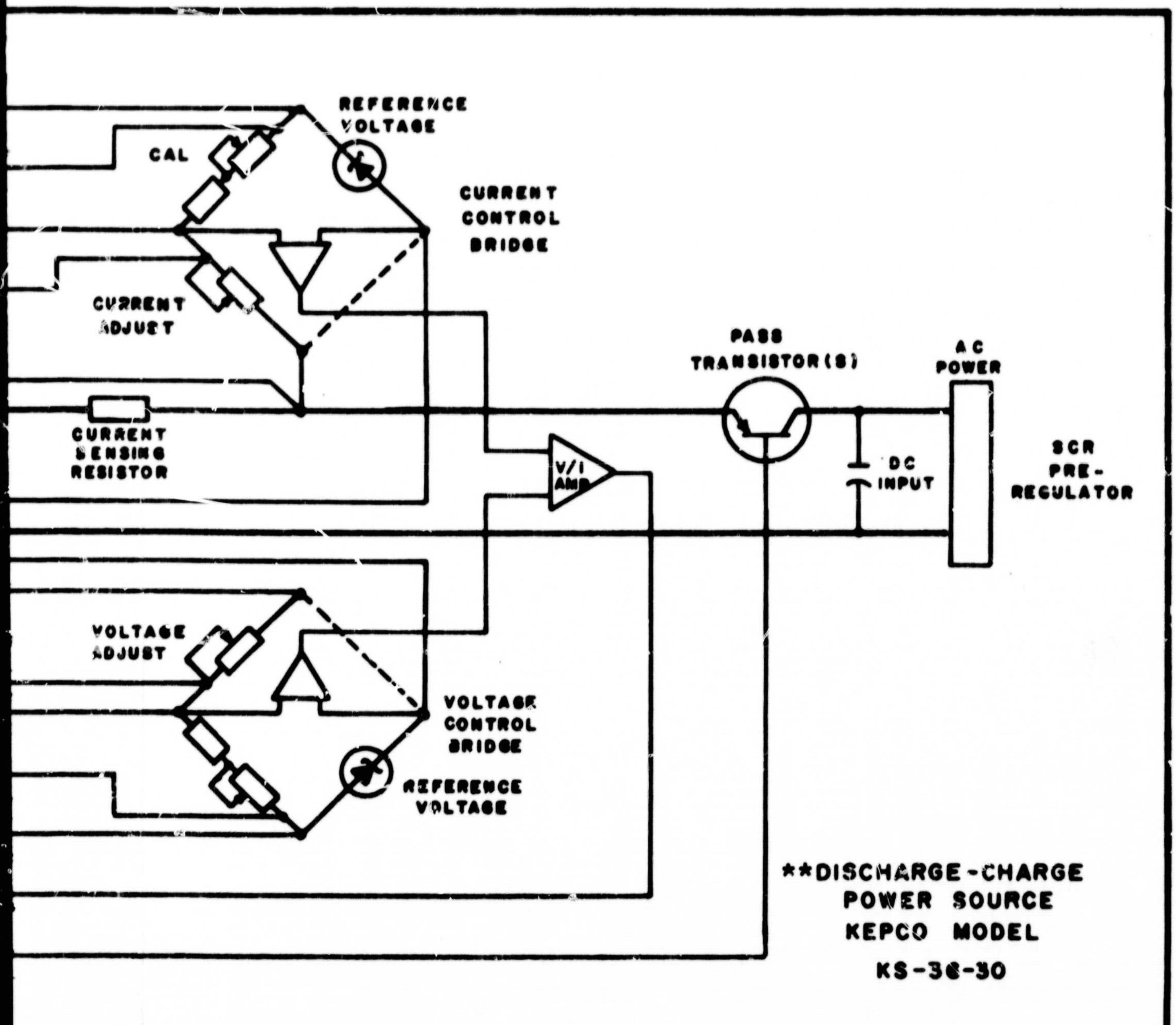
FOLDOUT FRAME 1



*Drawing from Kepco, Inc., "A Model DPD-1 Programming Decade A-40894," Instruction Manual, 1968.
**Drawing from Kepco, Inc., "Voltage/Current Regulated Power Supply," Instruction Manual KS 36-30, 1964.

Figure 32. Power-Supply and Programmin

FOLDOUT FRAME 2



de A-40894," Instruction Manual, 1968.
upply," Instruction Manual KS 36-30, 1964.

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Figure 32. Power-Supply and Programming-Decade Interconnections

to a modular composite unit is to incorporate the basic instrumentation methods used by commercial manufacturers of independent units. A modular digital-programming system is designed to control the output voltage and/or current to their respective programmable power supplies. Each E, I variable requires an input-programming keyboard, a digital-programming storage register, and a digital-programming decade to interface the power supply. Figure 32 shows the last stage of the programming decade connected to a power supply.

For future design conceptions, the sequencer and command-logic section will be updated with solid-state logic, commanded from an internal module containing registers with memory-type controls. Remote commands to the programmer can implement larger command functions, bypassing the limited program positions of the 10-position matrix programmer.

Creating an independent chassis for the load-relay section will develop a method for designing modular units adaptable to the kind of load required. This modular separation is a possible answer to hardware designs, depending upon the specifications assigned to the load-switching relays.

Adapting the modular concept shown in Figure 5 provides ways and methods for designing a battery cycler that would meet the following experimental specifications:

- Hardware interface to supplies for current ranges up to 100 amps
- Hardware interface to supplies for voltage ranges up to 60 volts
- One, or two power-supply interfaces for cycling
- Remote or local-input control
- Real-time interexchange of modular sections

A design goal is to adapt a battery cycler to various experimental programs on a short notice.

CONCLUSIONS

This report discusses the studies and methods for controlling an experiment with a battery cycler. The concepts, in basic form, are related to battery research. This repor may help in current battery-test and evaluation methods used to design hardware and interface software.

John F. Davis, an engineering supervisor at GSFC, Wayne A. Hembree, an electronic engineer at GSFC, and Lyman J. Leuice, an electromechanical designer at SJI Industries, Incorporated, contributed to the text of this document.